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Petroleum Technology

MARCH, 1952

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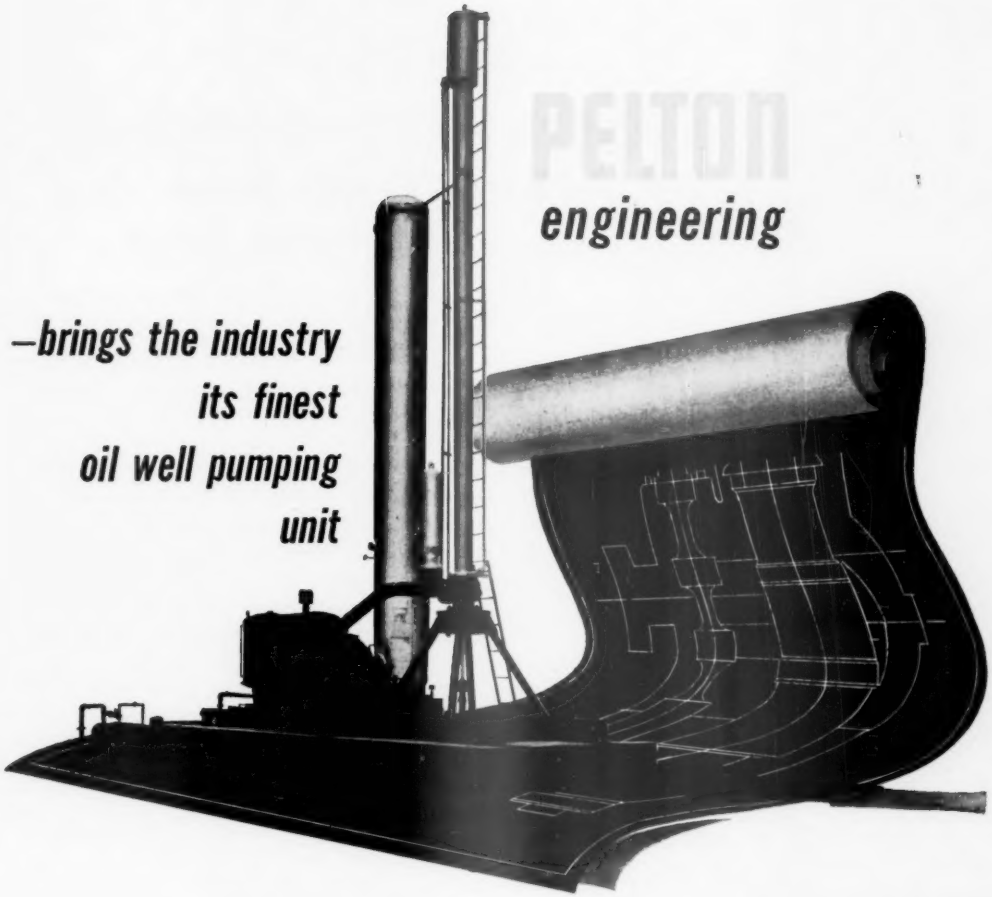

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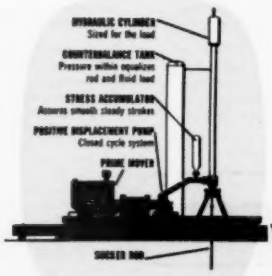

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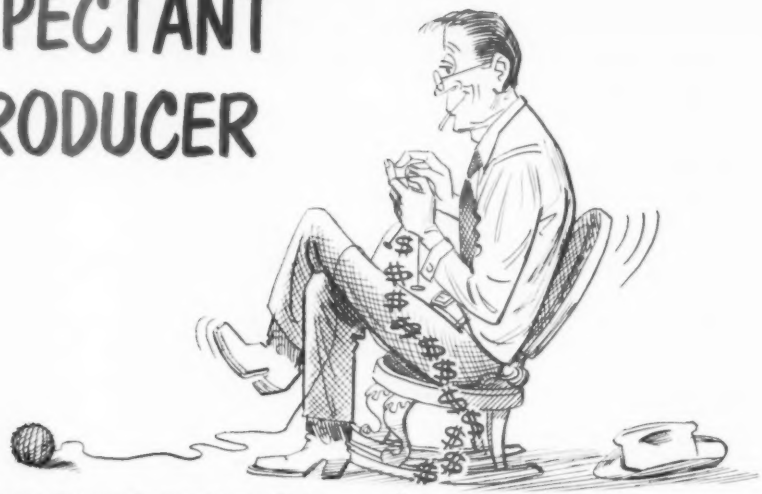
THE CASE OF THE EXPECTANT PRODUCER



Expecting his newly discovered reservoir to add up — barrel for barrel, dollar for dollar? Perhaps. But it's a long pull from bottom of the hole to the bank.

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Journal of Petroleum Technology

Vol. IV MARCH, 1952 No. 3

TABLE OF CONTENTS

Editorial Features — Section 1

Production and Development in the United States During 1951 11

Technical Note: A Note on the X-Ray Absorption Method of Determining Fluid Saturation in Cores, by T. M. Geffen and R. E. Gladfelter 15

The Location of Oil Prospects by Use of the Drill, Reported by W. M. Marshall 17

Some Economic Aspects of Well Spacing, Reported by W. B. Davis 18

Petroleum Transactions

Lost Circulation Corrective: Time Setting Clay Cement, by J. U. Messenger and J. S. McNiel, Jr. 59

Improved Multiphase Flow Studies Employing Radioactive Tracer, by V. A. Josendal, B. B. Sandiford and J. W. Wilson 65

Engineering Study of the Cook Ranch Field, Shackelford County, Texas, by Wallace W. Wilson 77

A New Additive for Control of Drilling Mud Filtration, by R. A. Salathiel 85

Institute Affairs — Section 2

Drift of Things, by Edward H. Robie 1

Personals 2

Employment Notices 4

Petroleum Branch Membership 4

Advertisers' Index 8

On the Cover — On page 11 of this issue is a summary of petroleum production and development in the United States during 1951 which was compiled by members of the AIME Production Review Committee and presented last month at the AIME Annual Meeting in New York City by R. B. Gilmore. The chart on the cover, superimposed over a Magnolia Petroleum Co. refinery in South Texas, depicts petroleum production growth during the past five years.

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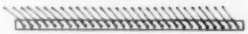

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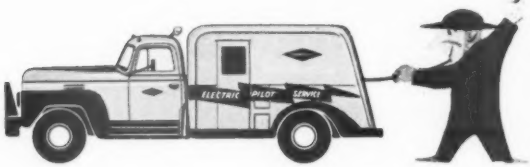

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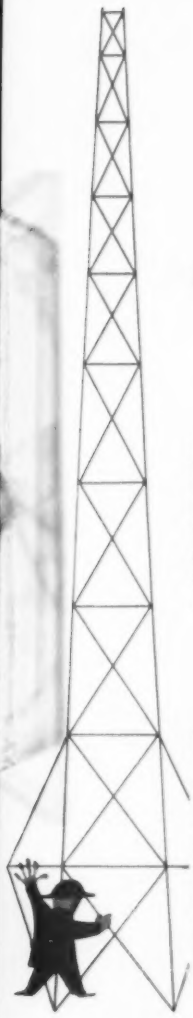

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Production and Development in the United States During 1951

Oil-Hungry Consumers, Demanding the Greatest Quantities of Petroleum Products in the History of the Industry During 1951, Are Expected to Increase That Demand and Push Production Rates Even Higher During the Current Year

PRODUCTION of crude oil in the United States during 1951 reached levels previously thought unobtainable except for short periods. Consumption of petroleum and its products surpassed even the most optimistic forecasts made in the recent past. An analysis of industry statistics indicates that demand for petroleum during 1952 will push domestic production to even higher rates, estimated by various forecasters at as much as five to ten per cent above 1951 levels.

Although imports into the United States of crude oil and products during 1951 were approximately the same as during 1950, it is probable that the Iranian situation prevented increases in imports during the last half of the year. Total exports, primarily of products, showed a material increase over 1950 but still did not attain the volume exported during and immediately after the close of the war. Exports of crude oil and products are expected to decrease in 1952 because of better adjustments in foreign production and distribution, and increases in foreign refining capacity, as well as because of increases in domestic demand.

13 Per Cent Increase in Crude

Although figures for many of the states are not yet complete, production of crude oil in the United States during 1951 was approximately 2,228,000,000 bbl, exceeding 1950 production by 257 million bbl, or 13 per cent. In addition, an estimated 241 million bbl of natural gas liquids were produced as compared with 182 million bbl produced in 1950. The total production of liquid hydrocarbons in the United States in 1951, therefore, was 2,469,000,000 bbl, or an average daily production of 6,764,000 bbl.

The record of production from natural gas is much more phenomenal than that of crude oil primarily due to operation of more major trunk pipe lines of which several recently have been completed or enlarged. Preliminary figures indicate that more than 8 trillion cu ft of natural gas were produced in the United States, of which approximately 50 per cent was transported to industrial and domestic centers. This represents an increase in consumption over 1950 of about 18 per cent. As would be expected, the major gas-exporting states of Texas, Louisiana, New Mexico, Oklahoma, and Kansas accounted for 85 per cent of the total gas produced, with Texas and Louisiana alone making up 73 per cent of the total.

A direct result of the increase in sales of natural gas was an increase in the number of new plants and in the capacity of previous plants constructed to treat the gas before marketing, and the resulting increase noted in the natural gas liquids recovered in these plants. Sales of liquefied petroleum gases during 1951 also set an all-time high. Domestic demand for these products is estimated to have reached 113 million bbl as compared with approximately 93 million bbl during 1950, an increase of 23 per cent.

Production in Texas accounted for the greatest increase in crude oil production from a single state, amounting to approximately two-thirds of the increase in the United States, or 163 million bbl. California with a gain of 27 million bbl, Louisiana with 26 million bbl, and Oklahoma with 21 million bbl provided most of the remaining difference between 1951 and 1950 production. Half of the states in which petroleum is produced established record highs of production. During 1951, North Dakota became the newest producing state in the nation and promises to become one of the more active areas for exploration and development during 1952.

Almost 57 per cent of all liquid hydrocarbons produced in the nation came from the Gulf Coastal states of Texas and Louisiana, and with the inclusion of production from the other southwestern states of New Mexico, Arkansas, Oklahoma, and Kansas this figure is raised to 73 per cent of total production in the United States.

California, with about one-sixth of the nation's current production is an independent unit, geographically and economically. It exports minor amounts of oil and imports no domestic oil, though it imports substantial quantities of natural gas and is preparing to take more. Establishment of a record crude production of 354,700,000 bbl is noteworthy when it is considered that the Elk Hills Field (which is a Naval Petroleum Reserve) remained practically shut-in. This field probably is capable of producing some 90,000 B/D and was actually producing 65,000 B/D during the last war. Under present operating practice the field produces only to test the potentialities of new completions or conditions in the older pumping wells. The daily average production from Elk Hills during 1951 was approximately 6,700 B/D. With a somewhat abnormal demand as a result of defense activities in Pacific areas, stocks reached a minimum economic level under prevailing demand. Although defense requirements are unpredictable, it is possible that should this demand continue it may be limited by the level of current new supplies in California or by shifting a portion of military requirements to other areas.

More Completions, Fewer Dry Holes

The record for production, established in the United States in 1951, is a direct function of the number of wells drilled.

Production and development figures contained in this report were gathered by members of the AIME Production Review Committee. The data presented here were given at the Annual Meeting of the AIME in New York City last month by R. B. Gilmore, vice-chairman for Domestic of that Committee.

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which reached a total of almost 45,000. This figure includes some 1,400 wells normally classified as service wells. On Jan. 1, 1952, there were nearly 450,000 producing oil wells in the United States. In the 13 states in which new production records were established were located 65 per cent of the total completions and 70 per cent of the oil wells completed during the year.

Although the more than 23,000 oil wells completed are slightly fewer than during 1950, the 3,100 gas wells completed are the most since 1947 and indicate to some extent the increased value of natural gas. The most serious consideration in these well statistics is that the 16,800 dry holes drilled are twice as many as completed in 1946 and the ratio of successful oil and gas completions to dry holes has decreased from 2.4 to 1.6 during this five-year period. This ratio is directly affected by the number of exploratory wells drilled which represent almost 25 per cent of the total completions. During 1951, 23 per cent more exploratory wells were drilled than in 1950, during which year less than 20 per cent of completions were exploratory wells. It is natural that this comparison should be true. The intensified search for petroleum reserves and the increased drilling density in areas already known to be favorable for production result in a greater percentage of dry holes.

If exploratory wells are limited to those drilled on a structure or in a geological environment never before productive, a classification adopted by Dr. Lahee in the AAPG, the record for recent years, with the most scientific approaches to discovery ever available, indicates only one successful well for every nine drilled. The persistence of this ratio is evident during 1951 with more than 10,000 wildcats drilled, which resulted in the discovery of almost 1,000 oil fields or new producing areas and more than 200 gas fields. New producing horizons and extensions to previous producing areas resulted from the successful completion of some 600 oil wells and 100 gas wells.

Figures published by the *Oil and Gas Journal*, in their annual review and forecast issue, indicate that discovery of new fields, new producing reservoirs, and extensions to areas previously producing, together with revisions in estimates previously made, resulted in an increase in crude oil reserves of more than one billion bbl after deducting production during 1951. California, with approximately 15 per cent of the reserves in the United States, is the only major producing state which showed a net decrease in reserves at the end of the year. Natural gas and natural gas liquids reserves also showed corresponding increases as a result of 1951 developments.

Williston Basin Discovery

Activities in 1951 gave added significance to new areas previously classified as future oil provinces of the United States, and tended to reverse the trend of the past few years toward discovery of smaller fields which, in total, did not add appreciably to reserves. Perhaps the most important single development was the discovery of oil in the Williston Basin in North Dakota early in 1951. The discovery well, originally completed in sediments of Devonian Age, was later recompleted in the Madison lime of Mississippian Age and it is possible that additional reservoirs may be proved productive on the same structure in which this well is located. This major basin area is centered in western North Dakota and extends into South Dakota, the eastern part of Montana, and northward into Canada. At this time, it appears that sediments of Ordovician, Devonian, and Mississippian Ages are of primary importance, with possibilities of production also in reservoirs of Silurian, Jurassic, and Cretaceous Ages.

It seems probable that accumulation of oil and gas will occur both on anticlinal structures and in stratigraphic traps. Most likely stratigraphic type traps are unconformities and wedgeouts on the eastern side of the basin. Reef conditions, similar to those which now are providing the bulk of production in Canada, are present not only on the eastern side of the basin but in other parts as well. Continued successful exploration in North Dakota, and greatly increased activity in this area, indicate the possibility that this area may become one of the major producing areas in the United States.

Activity in the Denver-Julesburg Basin Area of western Nebraska and eastern Colorado increased materially during 1951. In Cheyenne County, Nebraska, where production was first discovered in 1949, seven new oil fields and one new gas field were discovered during 1951. Three oil fields were discovered in adjoining counties in Nebraska but, to date, production from all of these fields is restricted because of limited pipe line facilities. Exploration in this area seems to indicate that most of the individual fields will be comparatively small in areal extent. Present production of both oil and gas is from sandstones of the Dakota Group of Cretaceous Age, varying in depth from 3,400 to 7,400 ft. A few deeper wells have been drilled without finding production from zones below these.

Colorado had a record number of new discoveries in 1951, most of which occurred in this same basin area. Twelve new oil fields and two gas fields were discovered in the eastern portion of the state in the same sedimentary group from which production is obtained in western Nebraska. Development in these areas also indicates that these fields probably will be small in area.

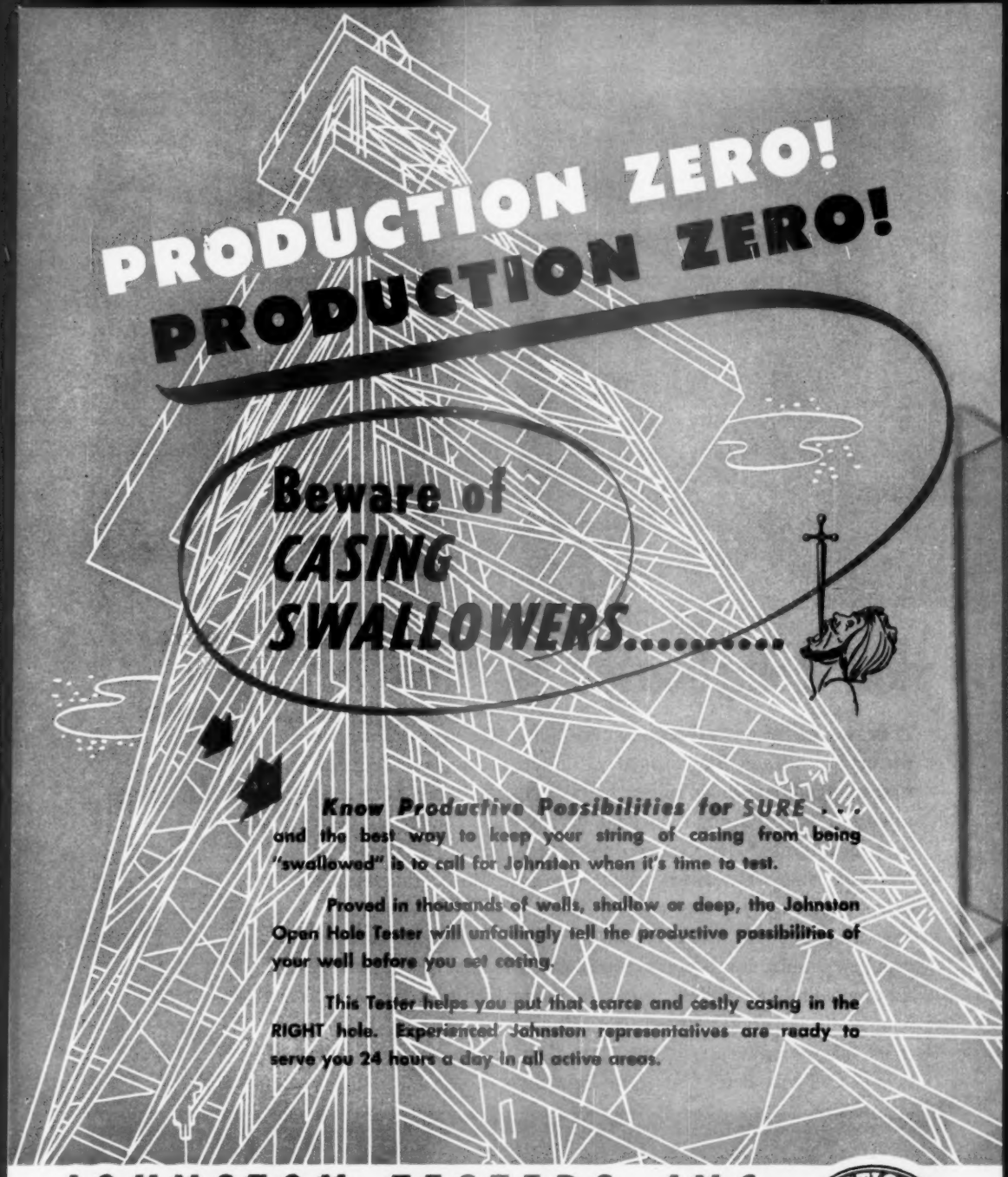
1,000 Rigs in Texas

The West Texas area, which contains the largest amount of proved reserves in the United States, continued to maintain a record pace of exploration and discovery of new fields and new reservoirs. More than 1,000 rigs are being operated in this area, representing a third of all drilling activity in the nation. New reserves were discovered almost daily. Of these, the reserves contributed by developments in the much discussed Spraberry trend have proved to be the most spectacular. The Spraberry reservoir is a silty sand, or a sandy silt, of Permian Age, which was deposited over most of the Midland Basin. Estimates of the possible productive area range from one-half to more than two million acres.

Estimates of ultimate recovery vary considerably but continued development of this reservoir indicates that the Spraberry trend will prove to be one of the major oil fields of the United States. During 1951, Spraberry wells produced approximately 11 billion bbl of the total of 12 million bbl which have been recovered to date. There are many production problems since these wells usually must be subjected to artificial stimulation before they will produce satisfactorily. Some 250 rigs currently are drilling in the Spraberry trend on proved, semi-proved, and wildcat locations, and although 17 separate fields, or producing areas, have been named, it is probable that many, if not all, of these areas will be combined with further exploration and development.

In spite of the centering of interest on the Spraberry trend, there were other significant developments in West Texas and the eastern part of New Mexico during 1951. Activity in New Mexico, along the trend of the Central Basin Platform in the eastern part of Lea County and in the southern part of Roosevelt County, resulted in major discoveries in reservoirs from Lower Permian down to and including Ordovician Age. Active exploration continued along the eastern shelf of the

Continued on Page 7, Section 2



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Technical Note 110——

A NOTE ON THE X-RAY ABSORPTION METHOD OF DETERMINING FLUID SATURATION IN CORES

T. M. GEFFEN AND **R. E. GLADFELTER,** STANOLIND OIL AND GAS CO., TULSA, OKLA., JUNIOR MEMBERS AIME

Lipson[1] has recently presented a technical note wherein theoretical considerations were used to demonstrate " . . . that the adsorption *vs* saturation relation for a linear absorption method is not necessarily a single valued function of saturation." It was concluded that the absorption *vs* saturation relationship is subject to the same hysteretic effect as is the flow behavior between the drainage and imbibition systems. It is the purpose of this note to show, by experimental results, that for the manner in which fluids are distributed in porous materials during fluid flow, the relative X-ray absorption *vs* saturation relationship is single-valued regardless of the saturation history.

The design of the apparatus used to measure relative X-ray absorption of cores undergoing fluid flow tests is similar to that described by Morgan, McDowell and Doty.[2] A few modifications have been incorporated in the design to increase sensitivity and simplicity of measurement. The sensitivity is such that for usual types of cores a recording pen movement of approximately 12 linear in. is occasioned between the recording of the core dry and when it is completely full of an absorbing liquid, a solution of approximately five per cent by volume of iodobenzene in a close-cut hydrocarbon fraction, or a solution of 50,000 ppm sodium iodide in water.

Two types of experiments were conducted, one in which the liquid was inside the core, and the other with the liquid outside the core. Tests with the liquid inside the core were run to cover the saturation range encountered in both the drainage (gas drive) and imbibition (liquid flood) flow systems. It is pointed out that the same core was used, but the tests were conducted at different times with the recording mechanism balanced at a different position. Therefore, the absolute values of relative X-ray intensity at any saturation are not the same in each test.

In the second type of test the same core was used, but this time its pore space contained only gas, and various thicknesses of oil contained in plastic cells were placed in front of the dry core. As before, the relative X-ray absorption was measured and compared to the quantity of oil in front of the core. The arrangement of the fluids with respect to the path of X-rays in these two types of tests represent fluid distributions of a wider difference than can be expected between that established in a core just due to imbibition and drainage saturation flow histories. Thus any deviation from a straight line relationship of the log of the relative X-ray intensity *vs* saturation calibration should be readily apparent.

Results of the laboratory tests are given in Fig. 1. A schematic diagram showing the position of the fluids with respect to the path of the X-ray beam is given for the two cases investigated. In the case where the oil existed outside the core (Case B), the log of the X-ray intensity ($\log_e I/I_o$) is related directly to the cell thickness (amount of oil in X-ray beam path). This correlation is

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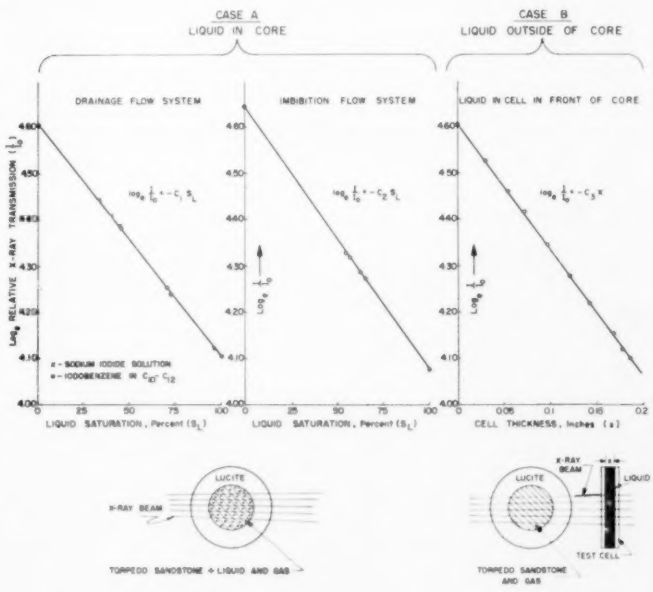

FIG. 1 — EFFECTS OF FLUID DISTRIBUTION ON X-RAY ABSORPTION.

Manuscript received in the Petroleum Branch office Jan. 18, 1952.

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A "surface wave" of radio energy is directed along the air-earth boundary from an "energizer" toward a receiver. As the surface wave progresses, individual "rays" peel off by refraction and enter the earth along a multitude of parallel ray paths. As the rays strike a reflecting formation, they are partially reflected back to the earth's surface, and refracted out again toward the receiver. Due to the electrical contrast that exists at the boundary of an oil field, the character of the reflected rays discloses the presence of oil.

HOW DOES RADOIL COMPARE WITH OTHER EXPLORATORY TECHNIQUES?

There is no close parallel. While other geophysical methods seek to define a "structural prospect," RADOIL has as its objective *the direct location of a worthwhile oil field.* This does not mean that RADOIL is designed to replace other methods. On the contrary, in its present development RADOIL is more suited to detailing than to reconnaissance work and, therefore, it is best employed in areas where a prospect has already been localized by other methods. *RADOIL is competitive with the drill,* not with conventional geophysical and geological techniques.

IS RADOIL A PROVEN METHOD?

The cumulative results of more than 300 commercial surveys, conducted during the past 15 years, show that RADOIL is more reliable in determining the presence of oil than conventional geophysical methods are in determining structural conditions favorable for the accumulation of oil.

WHAT DOES A RADOIL SURVEY COST?

Service charges for RADOIL compare favorably with the cost of other geophysical surveys, but it should be remembered that the chief effectiveness of RADOIL begins where other methods leave off; that it bridges the wide gap between a structural prospect and an oil field.

ON WHAT BASIS IS RADOIL AVAILABLE?

Experienced RADOIL field crews may be secured on a contract basis, as schedules permit; or on a non-exclusive license basis to responsible parties. An adaptation of the method, known as RADORE, has also been developed for use in locating ore deposits. RADORE is available to the mining industry on the bases described above for RADOIL.

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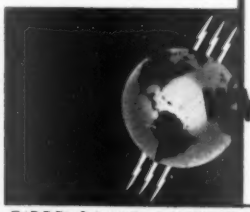

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The Location of Oil Prospects By Use of the Drill

Reported by W. M. Marshall
San Joaquin Valley Section

Current methods of locating drillable oil prospects have encountered an ever decreasing likelihood of success and unless there is either an increase in the resolving power of existing exploration techniques or the development of new methods, the oil industry must entertain widespread use of the drill in order to locate petroleum accumulations. Such a probability accentuates the general problem of reducing drilling costs. With this challenging note, William F. Bates, general drilling superintendent of the Pacific Coast area for the Shell Oil Co., opened an address to 45 members and guests of the San Joaquin Valley Section meeting last month.

When the means of reducing drilling costs are analyzed, three closely related major divisions emerge, namely, (1) equipment, (2) techniques, and (3) rate of penetration.

As a first approach to the reduction of drilling costs, consideration was given to lighter, more portable equipment which would exhibit the reliability of heavier rigs. This led to the selection of 3½-in. external upset, 9.3# "J" grade drill tubing with Acme type threads and tubing collars for use with a portable rig (150 horsepower, 90-ft derrick) which weighed only 70,000 lb. By January, 1948, eleven 6¾-in. holes ranging in depth from 1,800 to 5,600 ft were drilled with this equipment. An analysis of costs of the early holes indicated that savings of about $5 per foot resulted from use of the light-weight drill tubing and equipment. Two larger portable rigs were purchased subsequently and are currently being used for drilling larger and deeper (8,800 ft) holes with 4½-in., 9.8# tubes.

The benefit realized from use of this equipment emphasizes the possibilities of reducing drilling costs by sound engineering advancements.

Further advancements with regard to equipment might be realized by decreasing the size and weight of mud pumps. Perhaps this could be effected by supercharging smaller engines or using compact gas turbine engines should they prove adaptable.

The technique of drilling and coring has undergone but little change since its introduction to the industry. Further, the techniques of obtaining necessary subsurface information are costly, and yet have shortcomings in some cases. The electric log yields satisfactory data in some areas, but in others it is necessary to resort to expensive coring and testing. Before a substantial reduction in costs of sampling and testing can be realized, new tools must be conceived and perfected. In this regard, a tool is being considered for scraping the well bore at selected intervals and bringing samples to surface by wire line. A sidewall sampling device that traps formation fluid has been patented. Other techniques which may be instrumental in reducing drilling costs are a crossover circulating sub (used extensively in the Mid-Continent) to reverse the normal direction of circulation, and thus allow recovery of larger samples of the formation from the mud stream. Diamond drilling and coring, combined with all the advance techniques for conventional well drilling, holds good promise for reduced costs.

Contrary to the general concensus, the penetration rate in some areas is but little faster than it was several years ago. Results of tests indicate that increased bit weight increases the penetration rate if the mud circulation is adequate; yet, the only known technique for drilling a straight hole is to reduce weight on the bit. Therefore, the industry must develop methods of drilling a straight hole with increased weight on the bit. This might be accomplished by stabilizing the drill string through the use of concentric rubber bearings, one portion being vulcanized to the drill string and the other fitting loosely in the bore hole. Manufacturers of large gun barrels utilize a fully-stabilized cutting tool and core solid steel at the startling rate of 20 ft/hr; while the oil industry drills hard geological formations at a much slower rate. Promising developments concerning increased penetration rates pertain to the use of jet bits, to percussion action combined with rotary action and to the use of air as a circulating fluid. ★ ★ ★

New officers of the San Joaquin Valley Section are as follows:

Max C. Eastman, Chairman

R. P. Mangold, Program Chairman

Harry Campbell, Secretary

C. A. Davis, Treasurer

E. A. Armbruster, Membership Chairman.

ILLINOIS BASIN CHAPTER OFFICERS elected recently are, L to R, W. T. Roach, Tretolite Co., director; J. R. Vaughan, Sun Oil Co., vice-chairman (program); L. W. Swanbeck, E. A. Obering Co., chairman; R. L. Schick, Sohio Petroleum Co., secretary-treasurer; L. A. Mylius, consultant, director; and Daniel M. Moon, Schlumberger Well Surveying Corp., vice-chairman (membership).

Some Economic Aspects of Well Spacing

Reported by W. B. Davis
Mid-Continent Section

At a meeting of the Mid-Continent Section Reservoir Study Group held Jan. 29 on the University of Tulsa campus, Professor A. W. Walker gave an informal discussion of some studies on the economic aspects of well spacing.

Head of the Department of Petroleum Production Engineering at the university, Walker is presently serving as co-chairman of the Study Group Committee. He is also a member of the API district committees on well spacing and secondary recovery. The studies were made by graduate students under Walker's direction. Cases were considered in which it was assumed that there was no variation in ultimate recovery with well spacing and other cases were considered in which it was assumed that ultimate recovery would vary with well spacing. Each of the analyses considered several different well allowables. Each analysis considered a range of well costs and several different ranges of ultimate oil recovery. In all cases, the revenues and operating expenses were discounted to present worth at 4 per cent and 6 per cent per annum. For all the various cases considered, the net profit per unit acreage discounted to present worth was plotted against well spacing.

Under the ranges of ultimate oil recovery, well costs, etc., that are normally encountered in development drilling, most of the curves plotted showed an increasing net profit over the lower ranges of well spacing, reached a maximum and then decreased over higher ranges of well spacing. According to

A. W. WALKER

Walker's results, it is surprising how little difference it takes in the spacing to attain maximum net profit whether or not it is assumed the ultimate recovery varies with well spacing. For the range of well costs, ultimate recovery, etc., usually encountered in practice, it was found that the economically optimum well spacing varied somewhat, but appeared to average about 40 acres per well, which corresponds with much present day practice.

In the discussion that ensued, it was brought out that the conclusion that there is an optimum well spacing regardless of whether or not recovery varies with well spacing, is based primarily on the practice of discounting all revenues and expenses to present worth; however, since most oil companies operate, at least partially, on borrowed capital, this appears to be a valid assumption.

A symposium on the Spraberry sand development in West Texas was presented at the regular monthly meeting of the Section on Feb. 11. The principal speakers were Lincoln Elkins, R. F. Farris and C. V. Millikan.

Lincoln Elkins, a vice-president of the Petroleum Branch, and special projects engineer for the Sohio Petroleum Corp., discussed the reservoir engineering aspects of the Spraberry sands. His discussion included some data on the fracture porosity and on the performance of the wells. Farris, who is assistant operating superintendent of the Stanolind Oil and Gas Co., discussed drilling and completion problems. Millikan, chief engineer of the Amerada Petroleum Co., discussed production problems. ★ ★ ★

AIME President M. L. Haider Will Visit Texas Local Sections

Michael L. Haider, deputy coordinator of producing activities for Standard Oil Co. of N. J. and newly installed president of the AIME for 1952, will visit Local Sections in Texas the week of March 16-22. On Monday, March 17, President Haider will meet with the Student Chapter of the Petroleum Branch, AIME, at Texas Technological College in Lubbock. That evening he will talk to members of the Permian Basin Section in Midland. Topic for his talks will be Petroleum Branch and AIME affairs.

On March 18, he will fly to Bryan and will talk to the Student Chapter at Texas A&M College. The evening of March 18 will be spent by President Haider with members of the Gulf Coast Section in Houston.

On Wednesday, March 19, he will fly to Corpus Christi where he will meet with the Southwest Texas Section and on Thursday, March 20, he will proceed to Austin to visit with the Student Chapter at the University of Texas. Thursday evening, he will return to Dallas for a special dinner meeting of AIME members and their ladies in North and East Texas. At this function, he will present the Certificate of Honorary Membership in the AIME to E. DeGolyer (Feb. JPT).

MICHAEL L. HAIDER

On Friday, March 21, he will visit Kilgore and the East Texas Field and speak to members of the East Texas Section. On March 22 he will return to New York City. He will be accompanied on his trip by Joe B. Alford, Executive Secretary of the Petroleum Branch.

President Haider will attempt to visit other sections throughout the year. ★

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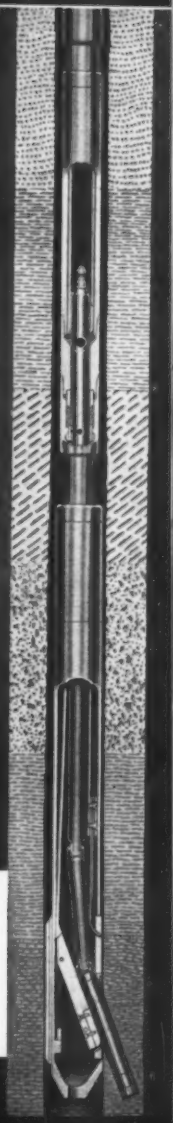

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DISCUSSION OF THIS AND ALL FOLLOWING TECHNICAL PAPERS IS INVITED

Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 408 Trinity Universal Bldg., Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 31, 1952. Any discussion offered thereafter should be in the form of a new paper.

LOST CIRCULATION CORRECTIVE: TIME-SETTING CLAY CEMENT

J. U. MESSENGER AND J. S. McNIEL, JR., MAGNOLIA PETROLEUM CO., DALLAS, TEX.

ABSTRACT

In the drilling of oil wells the control and prevention of lost circulation of the drilling fluid is a problem which is frequently encountered; in many cases existing materials and methods for alleviating this condition have not been adequate. For severe cases of lost circulation in which the simpler methods, such as application of various bridging materials to the mud system, have proven unsatisfactory, a new material and method for applying to the loss zones have been developed which appear to be superior to existing techniques in many respects.

The material, called a clay cement, is capable of being handled as a drilling fluid after initial mixing of the solid ingredients with water and may be pumped down the drill pipe and squeezed into loss zones. After a short period, the material develops a very high gel strength which seals off the zone against further losses of the drilling fluid.

In field tests, the process has been demonstrated to be a very effective method for combatting lost circulation.

INTRODUCTION

Methods of treating lost circulation in rotary-drilled wells by the addition of special materials to drilling fluids have long been in the process of development and are continuing to improve.[1] However, the annual drilling costs which can be traced directly to lost circulation difficulties still run into the millions of dollars. The loss of mud materials into highly permeable zones may range up to $50,000 per well in some areas. In addition to mud costs, excessive requirements of casing, cement, rig time, and the attendant blowout hazards further emphasize the importance of the need for improved methods of combatting lost circulation. The shortcomings of presently-used materials and methods have led to the development of a new lost returns material in the form of a time-setting clay cement. In field tests this material has proven very successful in plugging off loss zones, which other more conventional materials had failed to do.

REVIEW OF PRESENT CORRECTIVE MEASURES

The proper control of such operating factors as pump pressure, clearance between pipe and hole, and speed of running pipe in a hole[2] is of primary importance in preventing and minimizing lost circulation problems. These factors, however, concern matters of drilling technique and do not directly involve lost circulation materials. Aside from setting casing past loss zones, three principal methods are generally employed for the purpose of avoiding or combatting lost circulation: (1) adjustment in properties (principally density) of the drilling fluid, (2) addition of fibrous, flaky, granular or other types of bridging materials to the mud system, and (3) the application of cements to the loss zones. The latter method is usually employed only after the first two have proven unsuccessful. In Table I are listed some advantages and disadvantages of the common corrective measures. Frequently, a combination of bridging material and cementing material is used.[3] This combination is based on the premise that a bridge will

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch Aug. 7, 1951. Paper presented at the Fall Meeting of the Petroleum Branch in Oklahoma City, Okla., Oct. 3-5, 1951.

Table I — Methods of Correcting Lost Returns

	(1) Adjustment of mud properties (density and gel strength)	(2) Addition of bridging plastering agents to mud system.	(3) Use of cementing materials.
Types of Materials Used	1. Water 2. Clay 3. Weighting materials 4. Viscosity-reducing additives	1. Fibrous or flaky material 2. Size-graded granular solids	1. Gel cement 2. Quick-etting cement 3. Neat cement
Advantages	1. Economical 2. Requires no special materials	1. Tends to offer protection as soon as bridgeable loss zones are encountered in drilling 2. Treatment does not involve extensive loss of rig time	1. In some cases will protect against most severe types of loss 2. Will tolerate high pressure surges
Disadvantages	1. Applicable only to mild loss, usually at shallow depths 2. Correction requires close control and is often temporary	1. Will not protect against more severe types of losses where crevices and cavities exist 2. Will not withstand appreciable back-pressure surges 3. Loss of effectiveness while circulating often requires constant addition of new material	1. Loss of rig time because of: a. Placement time b. WOC time c. Time required to drill plug 2. Danger of sticking pipe 3. Possible deviation of hole while drilling plug 4. Adverse effects on mud properties by contamination with cement 5. Anticipatory treatment not possible

be built up within the loss zone at some distance from the well bore, affording a base against which a solid plug of cement might be formed.

Perhaps the most dependable method of overcoming lost circulation troubles is by method 3, the use of cementing materials. The expense and difficulties of this method are such however, that cementing materials generally are used in loss zones only where bridging and plastering materials have been proved ineffective. The use of gel cement and quick-set cement is common practice; however, neat cement is sometimes used in areas where gel cement is not available or in deep hot wells in which the mud weight is high. Shorter WOC times with quick-setting cement and a more easily drilled plug with gel cement has saved some rig time, but the danger of sticking pipe has made operators reluctant to "squeeze" in open hole.

Thermosetting plastics have been used for correcting lost returns and have shown some promise. While their applicability may involve less loss of rig time than do cements, they usually have no gel strength or bridging ability, and are difficult to apply, particularly in deep hot holes. Because of their limited applicability, of the fact that they are only partially effective, and of their high cost, they are not in wide use for this purpose.

Sodium silicate mixed with a clay slurry opposite the loss zones (by displacing one material down the pipe and the other down the annulus) has also been successfully applied to lost returns problems. However, the method of applying sodium silicate muds is difficult, requiring simultaneous control of pumping rates in pipe and annulus.

For the purpose of combatting lost circulation in cases where the simpler and more expedient methods have proven unsuccessful, a time-setting clay cement and technique of application have been developed which do not suffer many of the limitations of other materials and methods.

PROPERTIES OF TIME-SETTING CLAY CEMENT

Time-setting clay cement, as referred to herein, consists of an aqueous slurry of an especially selected clay, a smaller amount of an aluminum silicate to increase the strength of the set clay cement, and a retarder for increasing the pumping time of the slurry during application. The properties of the slurry immediately after mixing are such that it may first be pumped down a well to a highly permeable zone responsible for lost circulation and then squeezed into such a zone. After a relatively short period, the gel strength of the slurry increases to a very high level and becomes a plastic-like material with sufficient strength, in most cases, to seal off the zone against mud losses during subsequent drilling operations.

The physical properties of the slurry immediately after mixing closely resemble those of a highly thixotropic drilling mud. In the following table are given the properties of a typical time-setting clay cement slurry. In Fig. 1 are shown the Stormer initial and 10-minute gel strengths and API 30-minute water loss values of freshly mixed clay slurries as a function of the concentration of clay cement solids. The relatively low water loss level and high gel strength of the slurry immediately after mixing constitute added benefits for the application to which the clay cement has been designed. The

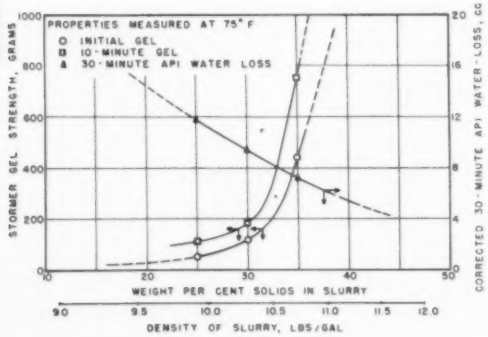
PROPERTIES MEASURED AT 75° F
O INITIAL GEL
□ 10-MINUTE GEL
Δ 30-MINUTE API WATER LOSS
STORMER GEL STRENGTH, GRAMS
CORRECTED 30-MINUTE API WATER-LOSS, CC
WEIGHT PER CENT SOLIDS IN SLURRY
DENSITY OF SLURRY, LBS/GAL

FIG. 1 — EFFECT OF SOLIDS CONCENTRATION OF TIME-SETTING CLAY CEMENTS ON INITIAL AND 10-MINUTE STORMER GEL STRENGTH, AND CORRECTED API 30-MINUTE WATER LOSS.

low water loss of the slurry makes possible squeezing opposite a highly permeable zone without danger of a flash set and the attendant hazard of stuck drill pipe, whereas the high gel strength aids in obtaining efficient displacement of formation fluids or drilling mud present in the loss zone. This latter property is essential in obtaining effective plugging of the loss zone.

Properties of a Typical Time-Setting Clay Slurry

Total Solids	35 wt per cent
Density of Slurry	10.7 lb/gal
Initial Stormer properties:	
600-rpm viscosity	250 cp
Initial gel	400 g
10-minute gel	800 g
Water-loss (30-minute API, corr.)	7 cu cm
24-hour equivalent Stormer gel (aged at 160°F)	40,000 g

Fig. 3 shows data on the effect of clay cement solids concentration on the strength or hardness of the clay cement after static aging for 24 hours at 170°F. The strength of the clay cement is expressed in terms of depth of penetration obtained with an ASTM penetrometer in which a cone with an apex angle of 50° was substituted for the conventionally employed needle. Use of this type instrument became necessary inasmuch as the clay cements containing as much as 35 weight per cent solids had strengths far in excess of the limits of the previously used gel strength measuring equipment. As might be anticipated, the higher solids concentration gave considerable lower penetration values, indicating greater strengths of the clay cement.

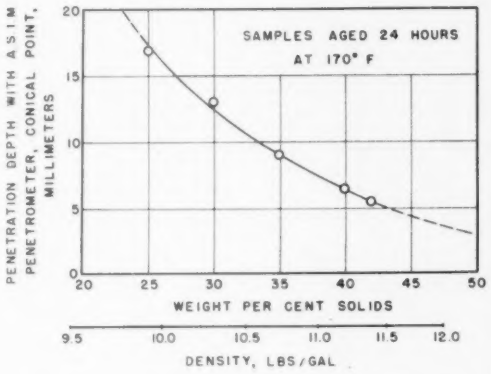
PENETRATION DEPTH WITH A S I M PENETROMETER, CONICAL POINT, MILLIMETERS
SAMPLES AGED 24 HOURS AT 170° F
WEIGHT PER CENT SOLIDS
DENSITY, LBS/GAL

FIG. 3 — EFFECT OF TIME-SETTING CLAY CEMENT SOLIDS CONCENTRATION ON STRENGTH OF CLAY CEMENT.

TECHNIQUE OF PLACEMENT

Time-setting clay slurries have been applied thus far only to loss zones against which plastering and bridging materials have proved to be relatively ineffective. The method of application closely resembles a cementing operation.

The time-setting clay slurry is preferably placed in a well by using conventional cementing equipment wherein the clay cement solids and mixing water are jet-hopper mixed and then pumped directly into the drill pipe. In certain areas, particularly in application to shallow loss zones, it should be feasible to utilize regular mud pumps and eliminate the need for cementing equipment.

On the basis of field experiences with these slurries, the following general procedure of placement has been developed.

1. Drill pipe is run, preferably open-end, to a point opposite or slightly below the loss zones.
2. An attempt should be made to establish at least partial circulation, using the cementing pumps, for the purpose of clearing the hole in the vicinity of loss zones of other materials which may have accumulated from former operations.
3. The time-setting clay cement slurry is "spotted" against the loss zones by being displaced down the pipe with the drilling fluid available at the well.
4. The slurry should be pumped into the hole until mud returns are obtained and then the blowout preventers closed. If the amount of clay cement placed is sufficient to plug the loss zone and if the fluid level is so far down the hole that returns cannot be established by forcing clay cement up around the drill pipe, the hole should be filled with drilling fluid through the fill-up line after one-third to one-half of the clay cement has been displaced against the loss zone, and if the hole then stands full or flows, the blowout preventers should be closed. This technique has been used and is satisfactory where the loss zone is below or within a short distance above the end of the drill pipe.
5. An attempt should be made to obtain a positive squeeze pressure (annulus pressure) sufficient to withstand the differential pressure which the loss zone is expected to withstand during further drilling operations. In order to allow more of the slurry to penetrate into the loss zones without exceeding squeeze pressures which may cause the formation to be fractured at other weak points, the pumping rate may be reduced toward the completion of the squeeze.
6. After all of the slurry has been displaced from the pipe, pressure should be maintained on the closed system for the

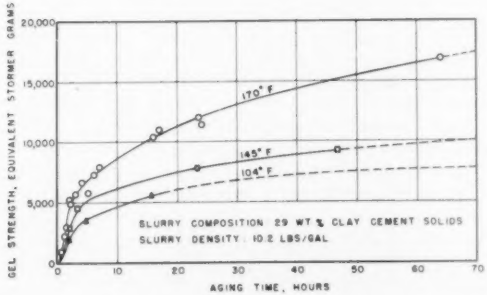

FIG. 2—EFFECT OF AGING TIME AND TEMPERATURE ON GEL STRENGTH OF TIME-SETTING CLAY CEMENT.

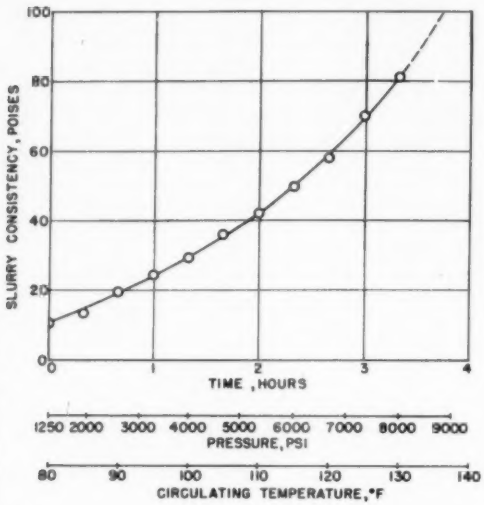

FIG. 4 — PUMPING CONSISTENCY OF CLAY CEMENT AS AFFECTED BY SIMULATED WELL CONDITIONS DURING PLACEMENT.

duration of the setting period or for whatever period is considered safe under the specific conditions. Undesirable swabbing effects due to the withdrawal of the pipe from the plug are largely eliminated by having the drill pipe placed so that a minimum of clay cement gets up around the pipe. Under conditions where clay cement was thought to have been up around the drill pipe, swabbing effects resulting from the withdrawal of the pipe have not caused any perceptible damage to the plug applied to the loss zone.

7. After removing the pipe from the hole, a wire line may be run to establish the location of the top of the clay cement. From this information, the amount of clay cement squeezed into the formation may be estimated.
8. If the formation temperature is above 150°F, the clay cement plug may be drilled after only a short waiting period of one to three hours. For lower temperatures a waiting period up to ten hours should be allowed.
9. In drilling out the clay cement in the hole, the bit is lowered to the top of the plug and drilled through at a rate no greater than ten feet per minute.

PERFORMANCE OF TIME-SETTING CLAY CEMENT IN FIELD APPLICATIONS

Lost returns zones in 12 wells located in six fields have been treated with time-setting clay cement. A summary of these applications is given in Table II. In all these wells, the loss zones are considered to have been relatively severe, and the application of clay cement was made only after attempts to seal off the zones by other means (bridging materials, and in some cases, portland cement were employed). It is to be noted that, in most instances, returns were regained after application of the clay cement. In the two cases where circulation was not regained, drilling proceeded with partial to complete loss of circulation until casing was set past the loss zone.

Several of the applications have been in relatively deep wells. To illustrate the pumpability of time-setting clay cement, the material was tested in a high pressure, high-temperature cement consistometer. In Fig. 4, the consistency-pumping time characteristics of a clay cement slurry containing 38 weight per cent solids are shown. The pressure and temperature schedule employed is also shown. These data indicate that pumping periods of satisfactory length are realizable with clay cements providing, in many instances, a greater flexibility in placement operations than is available by other methods.

Attention should be called to the shape of the pumping curves for clay cement and conventional cements. While the pressures at which clay cement can be safely pumped are generally higher than those for conventional cement, its setting curve shows that it does not exhibit a rapid set near the limit of its pumpability. In deep hot holes, it is recommended that the drill pipe not be filled with clay cement because of its high gel strength. However, pumpable batches of from 15 to 30 bbl have been applied easily and found very effective in restoring circulation under relatively high temperature conditions.

CONCLUSIONS

As a result of the field trials conducted with this material, the following advantages of time-setting clay cement over other materials and techniques for combatting lost circulation have become apparent.

1. Because of its low water loss, a time-setting clay cement slurry can be safely squeezed in open hole and up around the drill pipe. There is no danger of sticking the drill pipe as a result of flash-setting of the clay cement.
2. Because of its high gel strength, a time-setting clay cement slurry is resistant to dilution by formation waters and the drilling fluid, and can be used to fill large cavities and crevices.
3. Longer loss zones can be treated at one time than is practical using conventional cementing materials, and because of the low density and high gel strength of clay cement, the likelihood of success is enhanced.
4. Because of the much lower final strength of clay cement as compared to conventional cements, plugs may be drilled more rapidly and with much less danger of deviating the hole.
5. No tools have to be set to keep the slurries from coming up around the drill pipe inasmuch as the pipe may be withdrawn from the clay cement surrounding it after placement.
6. Unlike cements, time-setting clay slurries will not impair the physical properties of a mud to any appreciable degree.
7. Time-setting clay slurries cost less to use than common cement because they require less WOC time and less time to drill.
8. Because of the low water loss of clay cements, the possibility of further damage and weakening of formations resulting from filtrate effects is largely eliminated.

In its present stage of development, the application of time-setting clay cements has limitations in certain cases. For example, because of the cements' lower strengths, large quan-

Table II — Summary of Field Applications of Time-Setting Clay Cement

Case No.	No of Jobs	Loss Zones Treated					Clay Cement Application Data		
		Estimated Depth ft	Formation Temperature °F	Type of Loss Zone	Mud Loss, Bbl/Hr Before Treatment	Mud Loss, Bbl/Hr After Treatment	Amount Placed bbl	Calculated Amt. Squeezed into Formation bbl	Slurry Density lb/gal
1	2	6,520-6,760	100-120	Fractures	25	None	125	32	10.8
		5,970-6,480		Fractures	25	None		38	
2	5	5,500-6,650	100-120	Fractures	Complete	None	522	372	11.1
3	6	6,650-6,660	100-120	Fractures	Complete	Complete	467	320	11.0
4	2	4,295	100	Solution	Complete	Partial	426	399	10.8
		4,340		Channels		Complete			Containing expanded perlite
5	1	400-685	60-80	Fractures in Salt	Complete	None	225	171	11.3 Containing expanded perlite
6	1	4,864-4,899	180-220	Broken Limestone	25	None	184	95	11.0
7	4	4,230	180-220	Broken Limestone	Complete	None	177	96	11.0-11.4
		4,290			20	None			
		4,320			60	None			
		4,524			25	None			
8	1	5,655	180-220	Broken Limestone	Complete	None	34	11	10.9
9	1	1,091	100-140	Broken Limestone	Complete	None	21	*	11.2
10	1	11,343	200-230	Fractures	Complete	None	14	*	11.0
11	1	11,439-11,709	200-230	Fractures	Complete	None	23	*	11.0
12	2	10,600-11,000	200-220	Fractures	Complete (600 bbl/hr)	None	112	76	11.0-11.2

*Measurement of top of plug after squeezing not made.

tities are sometimes necessary to seal severe loss zones, especially where formation temperatures are low. This has been caused partially by the necessity for sacrificing some strength in the final set materials in order to retain other advantages previously discussed. While the material is not yet a cure-all for lost circulation problems, it has thoroughly demonstrated decisive advantages over other materials and techniques for curing a number of very serious types of lost circulation. The application of time-setting cements has thus become a valuable method for combatting these problems.

The authors wish to express their appreciation to the petroleum engineering and producing departments of Magnolia Petroleum Co. for their arranging and assisting in the field applications. Appreciation is also extended to B. F. Taylor for assistance and cooperation in conducting much of the experimental work. Acknowledgment is made to the management of Magnolia Petroleum Co. for permission to publish this paper.

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DISCUSSION

By W. C. Goins, Jr., Gulf Oil Corp., Houston, Tex.

The authors are to be complimented for making a fine contribution to an important phase of the lost circulation problem.

It is often found that the use of the common sealing materials such as mica, wood fibres, cellophane strips, etc., fail to seal off a loss. This makes the use of cement or highly viscous squeezing mixtures necessary, but their application is frequently attended with difficulties.

Gel-cement is probably the best material that can be used for losses at or near a casing seat, but complications arise if it is used in open hole, particularly where it is desired to squeeze the cement into a loss zone in a long open hole section. It must be squeezed from the casing through the long open hole section, or a packer must be set in the open hole. This latter measure is usually difficult, if not impossible. If the squeeze is made in soft formations there is danger of sidetracking the hole when the cement is drilled out. Also, chunks of cement may fall into the hole during later drilling and stick the pipe.

The sodium silicate squeeze mentioned by the authors has frequently been used successfully, but usually requires pumping in both the annular space and drill pipe to accomplish effective below-bit mixing of the silicate and fresh water mud. Two cementing trucks are usually necessary, and if the annular space does not stand full during the squeeze there can be no certainty that the squeeze mixture is going down the hole to the point of loss. It may turn up around the end of the bit and tend to stick the pipe.

The method presented in the paper would require only one cementing truck and would be simpler in general to apply. Since no annular space pumping is required, a packer could

be set at the casing seat for those jobs where the annular space does not remain full.

In the Gulf Coast area circulation can usually be regained through the use of the common bridging and plastering agents, but squeezes of the type described here become necessary in "pressure conditioning" formations. This is the problem which arises when the well loses circulation with a mud of a given density, and it is anticipated that a higher mud density will be required before casing is set. This makes it not only necessary to regain circulation but also to strengthen the loss zone to the point where it will circulate the anticipated high mud density. If there is considerable drilling to be done before the high pressure zone is to be penetrated then it is possible to gamble on the loss zone strengthening with time; but before the high pressure is encountered the well should be pressure tested to determine whether the higher density mud can be circulated. Frequently it cannot be circulated, and additional sealing measures are required, even though the well is experiencing no loss of circulation with the mud in use. Repeated squeezes with cement or other squeeze mixtures are often necessary before the well withstands the required pressure. It will be very interesting to follow the use of the authors' clay cement in this application. ★ ★ ★

IMPROVED MULTIPHASE FLOW STUDIES EMPLOYING RADIOACTIVE TRACERS

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ABSTRACT

Two radioactive tracers have been tested as a means of determining core saturation in multiphase flow studies. Cesium[134]chloride was tried as a water-phase tracer, but complications in its use in low permeability cores resulted from sorption of cesium by the core or water-wet pads. Iodo[131]benzene proved very satisfactory as an oil-phase tracer. The synthesis of iodobenzene from the sodium iodide as received from Oak Ridge is simple and direct. The tracer is insoluble in water and there was no evidence of sorption by any of the core materials used.

Use of the method to determine saturation profiles during capillary and dynamic desaturations and relative permeability measurements on oil-water and oil-gas systems is described. Comparisons of the dynamic and capillary methods of relative permeability determination were made using the tracer to check core saturation and saturation distribution. Other experiments are also described in which mobility of the oil phase at various saturations was measured by displacing labeled oil by flowing inactive oil. Similar experiments were made using water labeled with cesium 134.

INTRODUCTION

To be fundamentally sound, any laboratory method of determining relative permeability must meet, among others, the following requirements: (1) the core saturation between the pressure taps must be uniform, and (2) there must be uniform pressure difference between the phases in the region between the pressure taps. In practice it may eventually be shown that appreciable departure from either or both of these conditions may be permitted without introducing sensible error, but the magnitude of such error remains to be established. There is need then for methods of saturation determination which will determine the saturation profile in a core as well as the overall average saturation given by the gravimetric or material balance methods usually employed.

Methods which have received consideration include resistivity, X-ray absorption, gamma ray absorption, neutron diffraction, and radioactive tracers. The resistivity method has use in the determination of profile, but needs checking by independent means.[1] The X-ray method has been used successfully, but requires elaborate equipment and calibration.[2,3,4] At present gamma ray absorption is practical only for very large cores.[5] The neutron method[6] does not appear adaptable to measurement of saturation variations in short cores since it is a scattering method. Russell, Morgan and Muskat[7] employed radiovanadium in a study of the mobility of interstitial water. Coomber and Tiratsoo[8] used radioiodine as an oil-phase tracer and measured profiles in unconsolidated sand packs.

ADVANTAGES OF RADIOACTIVITY METHOD

A thorough discussion of the theory of radioactive tracers and the technique of using them to study the movement of fluids in sands is given by Coomber and Tiratsoo[8] and need not be detailed here. The method requires less equipment than the X-ray method; the counting problem is similar, but the generation and regulation of the radiation, which is a major problem in the X-ray method, is not required in the radioactivity method. In the X-ray method it is customary to add up to 20 per cent of absorber, usually an iodine compound, to the phase to be labeled, while in the radioactivity method a mere trace is sufficient. A possible disadvantage of the radioactivity method is that a disproportionate amount of the activity comes from the portion of the core nearest the counter, whereas the X-ray gives a true average saturation in the region traversed by the beam. On the other hand, this characteristic of the radioactivity method renders it peculiarly adaptable to study of certain types of radial variations in saturation.

As with the X-ray method, a tracer may be added to either the oil or water-phase. An oil-phase tracer is more generally useful, however, since it permits work on oil and gas in the

[1]References given at end of paper.

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presence of interstitial water as well as on oil-water systems. There are a number of available radioactive metals which can be considered for use as water-phase tracers, the only probable difficulties being sorption or ion-exchange on clays. However, except for oil-soluble, water-insoluble compounds that might be prepared from these metals, the selection of suitable oil-phase tracers is quite limited. Iodine 131 is a natural choice since it is readily available, relatively inexpensive, and has an acceptable half-life (eight days). A half-life somewhat longer than eight days would be desirable; however, this period allows experiments of three to four weeks duration, and there is the definite advantage that contaminated articles need merely be set aside for several weeks, after which they will be perfectly safe.

Coomber and Tiratsoo[7] used free iodine as an oil-phase tracer, which was feasible in their work since they found the distribution coefficient of iodine between oil and water to be about 2,500. However, the presence of reducing substances, such as hydrogen sulfide in either the oil or water, or the presence in the water of complexing agents would rule out the use of free iodine.

MATERIALS AND COUNTING EQUIPMENT

In the initial experiments cesium 134 in the form of cesium chloride was used as a water-phase tracer. Cesium 134 has a half-life of 2.3 years, and the energies of the principal gamma components of the radiation are 0.568, 0.602 and 0.794 mev. Six-tenths of a gram of cesium carbonate obtained from the Atomic Energy Commission having an activity of about 40 millicuries at the time of use was dissolved in three per cent aqueous sodium chloride solution containing a slight excess of hydrochloric acid to convert it to cesium chloride. For each experiment a 10 ml portion of this solution was added to 140 ml of three per cent sodium chloride solution, stirred under vacuum to mix and de-gas, and adjusted to a pH of five with sodium hydroxide.

In later experiments iodine 131 in the form of iodobenzene was used as an oil-phase tracer. Iodine 131 has a half-life of eight days and the energies of the principal components of the gamma radiation are 0.638 and 0.364 mev. Heptyl iodide had been prepared in this laboratory by exchange for use as a tracer.[8] However, the aryl halides are known to be more stable, and since the preparation of iodobenzene is simple, direct, and gives excellent yields, it was chosen for this work. Details of the preparation as carried out in this laboratory are given in Appendix A. No activity is removed from the labeled oil when shaken with concentrated hydrochloric acid, concentrated sodium hydroxide, or sodium bisulfite solution. A quantity of 25 or 50 millicuries of iodine 131 in 100 to 200 ml of oil was generally employed. The concentration of iodobenzene was 0.02 to 0.04, per cent.

The counting apparatus consisted of the following units:

a. Geiger-Mueller end window counting tube, Tracerlab TGC-1 or TGC-2 or Radiation Counter Laboratories Mark I-Model 13.

b. Predetermining count scaler, range of two to 8,192 counts, custom-built by Technical Associates, Glendale, Calif.

c. Printing interval timer, Tracerlab SC-5A.

A special shield providing two in. of lead around the counting tube was built and is shown in Fig. 1. Plug A is removable so that different sized openings can be provided. In most of the work a slit in front of the G-M tube one-fourth in. wide by one in. high was used. With a shield two in. thick and a half-inch sheath of Lucite around the core, the length of the core in view of the counter averaged about one-half in. when the counter was operated as close to the core as possible. Two in. of lead was desirable in the work with cesium. This thickness was also employed for the iodine, but further investigation might show that thicknesses of the order of one in. may be adequate. For better definition a narrower slit can be used, but it must be remembered that as the slit width is reduced, the amount of activity passing through the lead from the remainder of the core may become appreciable compared to the quantity passing through the slit, thus tending to de-

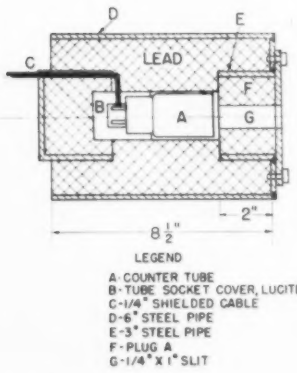


FIG. 1 — DETAIL OF COUNTING TUBE SHIELD.

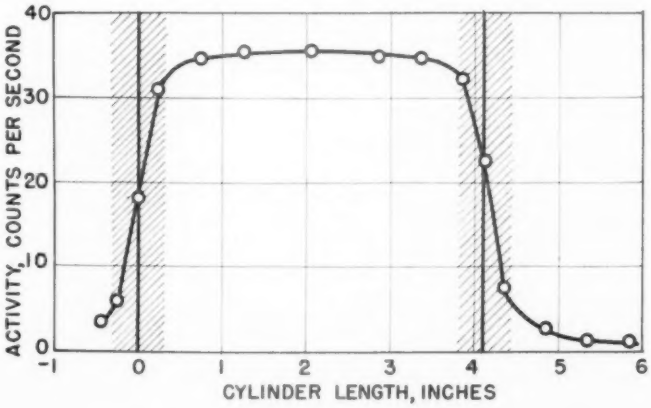


FIG. 2 — ACTIVITY PROFILE OF KEROSENE FILLED HOLLOW CYLINDER.

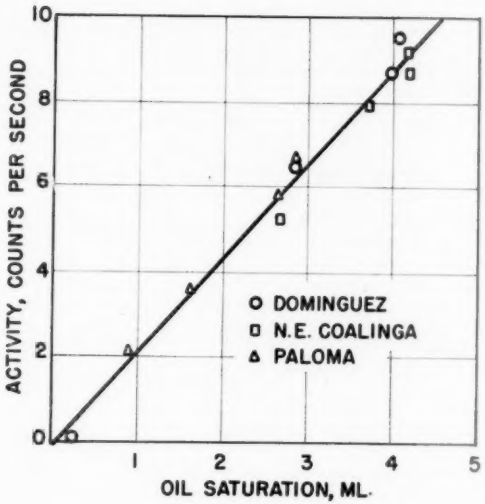


FIG. 3 — CORRELATION OF ACTIVITY IN NATURAL CORES WITH OIL SATURATION.

crease definition. The counter shield was clamped in the vise of a milling attachment to permit horizontal movement of the counter along the length of the core, which was held in a frame in front of the counter. The position was read to 0.01 in. on an attached scale. Originally, the counter was moved by turning the screw by hand, but later was motor driven to permit automatic counting.

CORRELATION BETWEEN ACTIVITY AND SATURATION

To check the definition obtained in this work, a Lucite cylinder two in. in diameter and with a hollow space one in. in diameter by about four in. long was filled with kerosene labeled with iodine 131 and scanned in the usual manner. The results are shown in Fig. 2. Geometric consideration and experimental results show that the activity can be expected to decrease over a distance of travel of about five-eighths in. as the field of view of the counter moves past the ends of the cylinder. This region is shaded on the graph. Over the remainder of the active region the profile is very flat.

To determine the applicability of iodobenzene as a tracer in natural cores containing clay, three samples representing widely varying clay types were selected.[10] Properties of these samples are listed in Table I.

Table I — Properties of Natural Cores

Field	Predominant Clay Type	Length in.	Diameter in.	Pore Volume ml	K = md
Dominguez	Kaolin, Montmorillinite	1.85	0.985	5.82	70
Paloma	Montmorillinite	1.83	0.985	4.23	18
N.E. Coalinga	Kaolin	1.92	0.985	4.60	925

The cores were mounted in Lucite[11] and saturated with three per cent sodium chloride solution. They were clamped vertically side by side in front of the G-M tube carriage, with a one-quarter by one and one-half in. vertical slit in front of the counter tube so that in each case nearly an entire core was in view of the tube. The cores were then subjected to capillary desaturation employing iso-octane labeled with iodo^{131}benzene. The activities within each core were measured at intervals during the desaturation for comparison with the oil contents as measured by the volumes of brine expelled. The results are given in Fig. 3. The relation appears to be linear, and there is fair agreement among the different cores in spite of the varying compositions and pore volumes and the fact that no special effort was made to obtain exactly the same distances between cores and counter tube. It would be desirable to check linearity by a method permitting greater accuracy of volume readings. Coomer and Tiratsoo,[9] by measurements in brass cells of varying thicknesses, found a non-linear relation between oil volume and activity, and stated that this was attributable to self-absorption. It is probable, however, that the non-linearity which they describe is principally the result of the distance effect (details are not given, but it appears that each increment of oil was farther from the counter). The distance effect does not apply in measurements on a core, where, if the saturation is uniform radially, the average distance between the counter and the core does not vary with saturation. There would be a slight non-linearity because the absorption by water differs from that by oil, and in the case of oil and gas the variation would probably be detectable (rough calculations indicate an error of not over two or three per cent).

After desaturation the cores were flooded to residual oil with brine and the activities measured. At a later date after

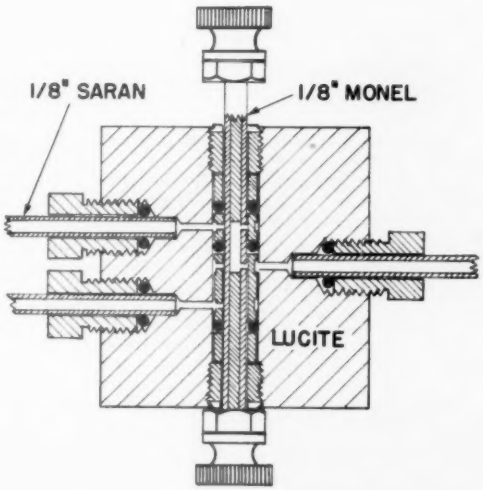
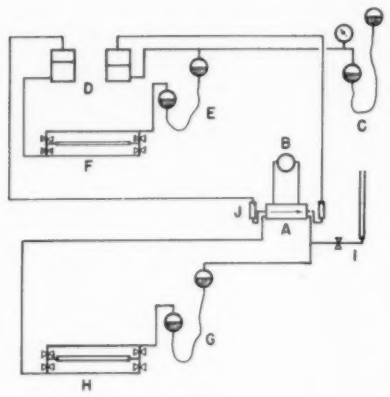


FIG. 4 — ZERO VOLUME DISPLACEMENT "O" RING VALVE.



LEGEND

A — CORE
B — GAGE
C — CAPILLARY PRESSURE HEAD
D — ACTIVE OIL RESERVOIRS
E — OIL PUMP
F — OIL FLOW METER
G — WATER PUMP
H — WATER FLOW METER
I — WATER RESERVOIR
J — ACTIVITY CALIBRATION CELLS

FIG. 5 — FLOW DIAGRAM OF CAPILLARY METHOD RELATIVE PERMEABILITY APPARATUS.

the activity had decayed to a safe value, the cores were subjected to a vacuum distillation to determine the true residual oil contents (Table II).

It is apparent that there was no significant sorption of activity by any of the cores. It should be pointed out that these cores were all water-wet and were initially saturated with water. Sorption might be more likely in dry or oil-wet cores.

USE OF RADIOACTIVITY METHOD IN FLOW WORK

The radioactivity method of measuring saturation as described above was used to measure saturation profiles during capillary and dynamic desaturation, to determine the mobility of oil and water in cores, and to compare the measurement of relative permeability by different methods.

It is believed that the methods of relative permeability determination in use can be classified as capillary and dynamic, the principal distinction being the method of bringing about saturation changes. The capillary pressure method[2] of relative permeability measurement has been described by many in the literature and is characterized mainly by the fact that the saturation is changed by applying capillary pressure across the non-wetting phase ports and the wetting phase semi-permeable membranes. In the dynamic displacement method[2] the phases are flowed simultaneously until no further saturation change is detectable.

Table II — Correlation of Residual Oil Saturation With Saturation Indicated by Activity

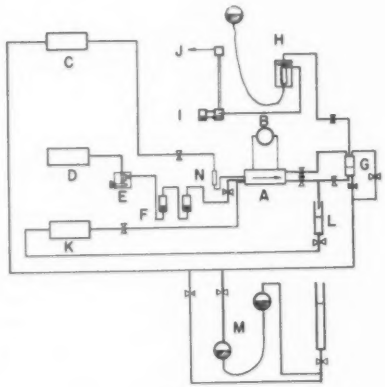
Core	Residual Oil Saturation, ml	
	Indicated by Activity	Found by Distillation
Dominguez	1.2	1.2
N.E. Coalinga	1.4	1.5
Paloma	1.2	1.4

DESCRIPTION OF FLOW APPARATUS

It is essential in working with radioactive fluids to maintain a high degree of reliability in the fluid system. Glass stopcocks and tubing were considered inadequate. Accordingly, zero volume displacement "O" ring valves, one-eighth in. diameter Saran tubing, and Lucite vessels were used. The Saran tubing was connected to the core, valves, and Lucite reservoirs by "O" ring fittings. Construction of the valves and fittings is shown in Fig. 4.

Capillary Pressure Method

The apparatus described herein differs from the usual set-up mainly in the fact that the pressure is measured through taps on the side of the core rather than at the ends. Also, the liquids are forced through the core by mercury head pumps rather than air pressure. The closed liquid flow systems prevent any change in the average core saturation during flow. Liquid flow rates were measured by movement of an air bubble



LEGEND

A — CORE
B — GAGE
C — OIL PUMP
D — GAS SUPPLY
E — FLOW REGULATOR
F — GAS SATURATOR
G — SEPARATOR
H — GAS PHASE BACK PRESSURE REGULATOR
I — GAS FLOW METER
J — VENT
K — WATER PUMP
L — WATER BURET
M — OIL PHASE BACK PRESSURE REGULATOR
N — CALIBRATION CELL

FIG. 6 — FLOW DIAGRAM OF DYNAMIC METHOD RELATIVE PERMEABILITY APPARATUS.

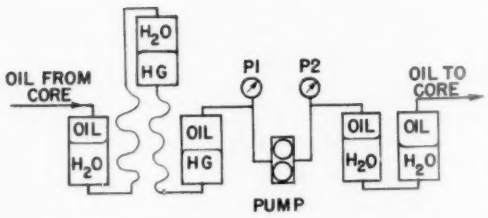


FIG. 7 — USE OF ZENITH PUMP AT LOW FLOW RATES.

in a precision bore tube. By means of the zero volume displacement valves the bubble could be moved in either direction or the tube by-passed. The capillary method apparatus for the oil-water system is shown in Fig. 5. A similar apparatus was used for oil-gas runs. The oil system in these runs was the same as shown in Fig. 5 except that a burette was added to measure the volume of oil desaturated from the core. The gas system was similar to that shown for the dynamic method in Fig. 6. However, the gas was introduced to the gas saturator at a constant pressure, the capillary pressure. A manometer was also added to measure the pressure head across the entire core. To start gas flow, the pressure at the outlet end of the core was reduced by lowering the mercury head on the back pressure regulator.

Dynamic Displacement Method

Referring again to Fig. 6, it will be seen that constant rate metering pumps were used in the dynamic flow experiments. Zenith* model 1/2B gear pumps (0.297 ml/rev) were found satisfactory when used in an arrangement as diagrammed in Fig. 7. A viscous oil (about 2,500 cp at 75°F) was metered by the pump, and by means of the mercury leveling bulb the pump suction pressure was maintained approximately the same as the discharge pressure. In this way, slippage in the pump was practically eliminated.

Pressure Measurement

Pressures were measured through the side taps by means of low volume displacement type gauges in both the dynamic and capillary method runs. Two types of differential pressure gauges were employed, an Aerojet** gauge with interchangeable diaphragms and a 0-20 psi Wiancko† gauge. Pressure drops as low as 0.12 psi were measured with suitable accuracy. The volume displacement of the Aerojet gauge with a 0.005 in. diaphragm is 7 cu mm per psi applied pressure while the Wiancko displaces 2.5 cu mm per psi. Both gauges operate on the principle of changing magnetic reluctance. Gauge outputs were recorded on a Foxboro Dynalog Recorder used in conjunction with simple bridge circuits.

With the Wiancko gauge, it was possible to measure the absolute pressures in the core directly. With the Aerojet gauge, it was necessary to match the core pressure with an applied pressure measured by a manometer.

*Zenith Products Co., West Newton, Mass.
**Aerojet Engineering Corp., Azusa, Calif.
†Wiancko Engineering Corp., Altadena, Calif.

Core Mounting

The Alundum and natural cores with end diaphragms and pressure taps were mounted in Lucite. Pressure taps were mounted only on the sides of the cores at a sufficient distance from the ends to minimize flow distortion. In those positions where unimpeded flow into the core was desired a plate of high permeability Aloxite was placed against the core. To make connections with the fluid lines, holes were drilled through the Lucite sheathing to the Aloxite plates against the core and backing the diaphragms. Fig. 8 illustrates a core mounted for a relative permeability study, comparing the dynamic and capillary methods in the oil-water system. Water-wet diaphragms and open ports were provided at the ends of the core for flow and along the side for pressure measurement.

Johns-Manville Snow Floss was the material usually used for water-wet semi-permeable membranes. It is an unconsolidated diatomaceous earth having a particle size of 1-2 microns. An oil pressure of 30 psi was required to displace water from

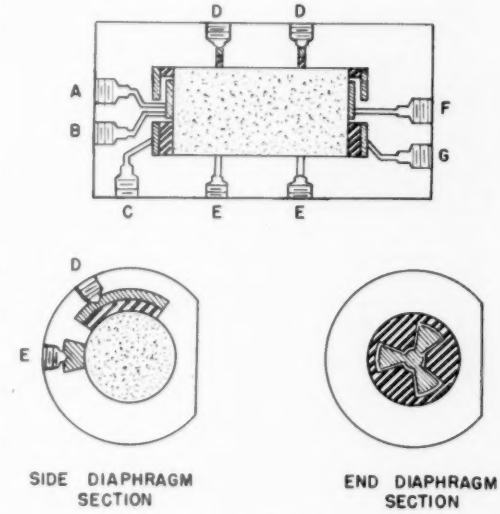


FIG. 8 — MOUNTED CORE FOR OIL-WATER RELATIVE PERMEABILITY MEASUREMENTS BY CAPILLARY AND DYNAMIC METHODS.

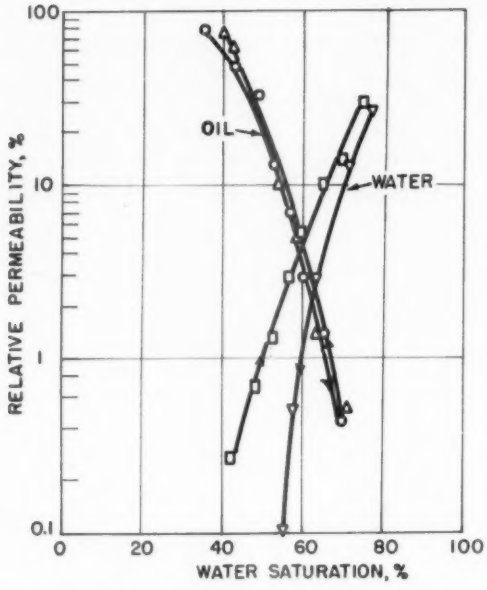


FIG. 9 — EFFECT OF THE DIRECTION OF SATURATION CHANGE ON RELATIVE PERMEABILITY, CORE A.

the material after it had been compressed by the mounting procedure. For oil-wet diaphragm material Coors No. 740 porcelain was treated with Dri-Film.

In order to mount the core, a number of Lucite sections were machined in such a manner that they could be fitted together to enclose the core and diaphragms. Snow Floss was pressed into the grooves in the partially assembled sections prior to insertion of the core. The sections were then cemented together and the assembly subjected to external pressure and heat.[11] The mounting was completed by drilling and tapping the Lucite for flow connections.

EXPERIMENTAL PROCEDURES

The cores were cut to the dimensions given in Table III.

The natural cores were cleaned in a Soxhlet extractor first with toluene and then with dioxane and dried at 220°F for about three hours. The Alundum cores were extracted in the same manner with constant boiling hydrochloric acid, successively extracted with water, methanol, toluene, and dioxane, and dried at 220°F. Pore volumes were then determined by weighing the cores saturated with kerosene. The kerosene was removed by another extraction with toluene and dioxane, followed by the usual drying. Following this, the cores were mounted as described above with diaphragms as indicated in Table III. Air permeabilities corrected for Klinkenberg effect were next determined. Cores A, B, and C were saturated with appropriate synthetic formation water and D, E, F, and G with three per cent sodium chloride solution. Brine permeabilities are indicated in the table. Cores A, B, and C were desaturated by the capillary pressure method using a close-cut redistilled kerosene (B.P. 420-500°F, viscosity 2.15 cp). Cores E, F, and G were similarly desaturated, but with iso-octane. The maximum capillary pressure employed was 15 psi.

In the studies of Core A, the kerosene used for desaturation was tagged with iodo^{131}benzene. The activities at five points along the core were measured, and from the values determined at interstitial water saturation the activity *vs* saturation calibration was established on the basis of a linear relation as found above. It was assumed that the core saturation was uniform at interstitial water; a better basis of calibration would be measurements taken when the core was 100 per cent saturated with the labeled fluid. Capillary pressure was increased in increments and oil and water effective permeabilities were measured after attaining equilibrium following each step. Activities were measured at the five points along the core to check uniformity and determine saturation. After the minimum brine saturation had been attained, the capillary pressure was

Table III — Summary of Core Properties

Core No.	Type	Diam. in.	Length in.	Pore Vol. ml	Porosity %	K_{air} md	K_w md	I.W.* %	Mounting** Inlet	Outlet	Side Taps
A	Natural	0.993	4.13	8.97	17.6	546	415	34.8	2-OH 1-SF	2-OH 1-SF	2-OH 2-SF
B	Natural	0.998	2.035	5.52	21.7	72.6	39.2	35.8	1-OH 1-SF	1-OH 1-SF	2-OH 2-SF
C	Natural	0.965	1.94	5.12	23.0	79.5	23.2	39.4	1-OH 1-OWC	1-OH 1-OWC	2-OH 2-OWC 1-SF
D	Alundum	1.047	3.98	14.4	26	80	—	—	1-OH	1-OH	none
E	Alundum	1.00	3.57	12.5	27.3	26.5	35	28.0	1-OH 1-SF	1-OH 1-SF	5-OH 5-SF
F	Alundum	1.00	3.545	11.17	24.4	21	22.9	28.0	1-OH	1-OH 1-SF	2-OH
G	Natural	0.985	1.85	5.82	25.0	—	70	34.0	1-OH	1-OH 1-SF	2-OH

*Residual water after application of 15 psi oil capillary pressure.
**OH = Open Hole, SF = Snow Floss, OWC = Oil-Wet Coors.

reduced to nearly zero, and the core permitted to imbibe brine. During the imbibition process relative permeability measurements were taken at only one saturation because the imbibition was extremely slow. Therefore, the core was flooded with brine to residual oil saturation, and another series of capillary method relative permeability measurements made during a second desaturation. Following this, the kerosene was flushed out with inactive kerosene since the activity had decayed to a low value. The core was transferred to the dynamic displacement method apparatus, and new labeled kerosene flowed until the inactive keronsene had been replaced. Oil was then flowed at 16.8 ml/hr and brine at 0.23 ml/hr. This resulted in an increase in brine saturation from 35 per cent to 43 per cent. The brine to oil flow rate ratio was then increased in steps to give additional points on the relative permeability curves, and finally only brine was flowed. With brine flow maintained at a high rate, oil flow was commenced at a low rate, and finally the oil to brine rate ratio was progressively increased to give relative permeability curves in the direction of increasing oil saturation.

Core B was treated in a similar manner.

A third core, C, was used for studying relative permeability of oil and gas in the presence of a constant amount of interstitial water. With the core in the restored state condition, desaturation was commenced using nitrogen, and the capillary pressure was increased in steps, with relative permeability measurements being taken at each point after equilibrium was attained. During this process, activity was measured at four positions along the core. Unfortunately, because of end diaphragm failure, only two oil relative permeability values could be obtained. After measurements at a capillary pressure of 4.5 psi, the nitrogen pressure was decreased to zero, oil was flowed through the core, and essentially all gas was removed by alternately increasing and decreasing the absolute pressure on the system. Dynamic studies were then begun by continuing oil flow at a high rate and starting gas flow at a low rate. Fine adjustment was obtained by means of a gas flow regulator.[14] After equilibrium was attained and pressure and gas flow rate measurements were taken, the oil rate was reduced, which resulted in an increase in gas rate and a decrease in oil saturation. The time required to come to equilibrium after changing rates varied from one to five hours. Finally, gas only was flowed at an increased rate (242 ml/hr), and after equilibrium was attained, the oil flow rate was increased in increments, and relative permeability data were taken in the direction of increasing oil saturation.

In order to evaluate brine mobility, Alundum cores D and E, in which radioactive cesium was employed as a brine phase tracer, were flooded with active brine to minimum oil, and then were swept with inactive brine.

Alundum core F and natural core G were employed in oil-gas (in the presence of interstitial water) dynamic flow studies similar to those described for Core C. Oil-phase mobility observations are reported herein.

RESULTS AND DISCUSSION

Saturation History

It has been recognized that the nature and sequence of changes in fluid saturation in porous media play an important part in fluid flow behavior, and these changes, which have conveniently been described by previous workers[15] as saturation history, should be considered when planning studies of such phenomena. In such work it is desirable to duplicate as nearly as possible the reservoir saturation conditions before initiating fluid flow studies. In relative permeability experiments designed to simulate conditions attending oil production, the core saturation should be brought to the restored state condition.[16] The correct saturation history permits the distribution of gas, oil and water in pores of the proper sizes. The distribution of the fluids within the pores appears to affect directly the relative permeability results, the pressure differences between the phases, the mobility of the fluids, the time necessary to reach equilibrium, and the quantity of oil which will remain in the residual state. To illustrate some of these effects, typical data are presented from relative permeability studies in which the radioactivity technique was employed to check saturation uniformity. These data rule out the possibility that the hysteresis effects could be attributed solely to non-uniformity in saturation.

The effects of the direction of the saturation change upon the dynamic displacement relative permeability curves obtained in studies of cores A and C are shown in Fig. 9 and 10. There is little difference in the oil relative permeabilities taken in the two directions in this example (Fig. 9), but there is a pronounced difference in the case of water. These results appear to be in agreement with those of Geffen, Owens, Parrish and Morse.[15] Water is normally the wetting phase, which fact causes it to be held more tightly by the reservoir sands. It

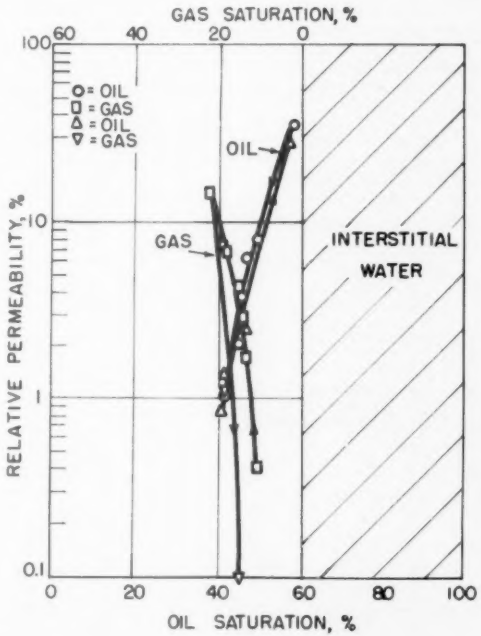


FIG. 10 — EFFECT OF THE DIRECTION OF SATURATION CHANGE ON RELATIVE PERMEABILITY, CORE C.

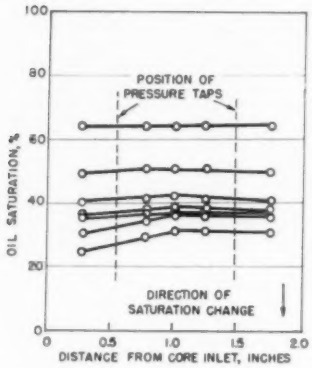


FIG. 11 — OIL SATURATION DISTRIBUTION DURING DYNAMIC TWO-PHASE FLOW OF OIL AND WATER IN CORE B.

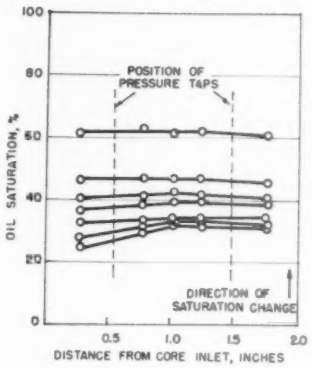


FIG. 12 — OIL SATURATION DISTRIBUTION DURING DYNAMIC TWO-PHASE FLOW OF OIL AND WATER IN CORE B.

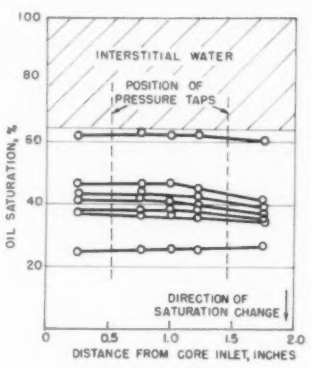


FIG. 13 — OIL SATURATION DISTRIBUTION DURING DYNAMIC TWO-PHASE FLOW OF OIL AND GAS IN CORE B.

was observed in water-wet sands that it was not possible after a certain saturation was reached by flowing oil and water at a given set of rates to duplicate the results by flowing at the same rates but in an opposite direction of saturation change. For example, in Fig. 9, a given set of oil and water rates resulted in a water saturation of 52.5 per cent during the direction of saturation change which represented oil production. The same oil and water rates resulted in a water saturation of 58.5 per cent when changing saturation in the opposite direction.

From Fig. 10 it can be seen that the effect of the direction of saturation change during gas and oil flow at interstitial water is quite pronounced. The relative permeability curve for gas during gas desaturation sharply approaches zero, probably because the gas phase becomes discontinuous.

From these observations the importance of changing the saturation in the proper direction according to reservoir conditions can be readily appreciated.

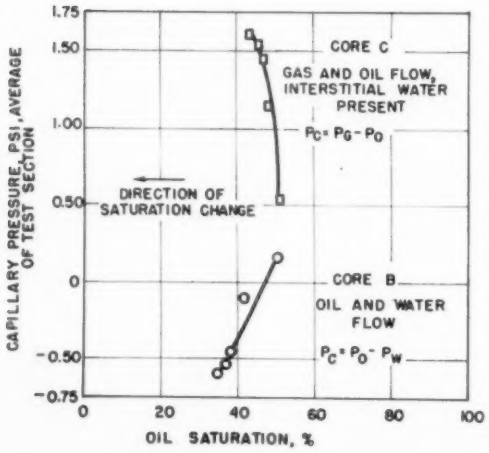

CORE C
GAS AND OIL FLOW, INTERSTITIAL WATER PRESENT
$P_C = P_G - P_O$
DIRECTION OF SATURATION CHANGE
CORE B
OIL AND WATER FLOW
$P_C = P_O - P_W$
CAPILLARY PRESSURE, PSI, AVERAGE OF TEST SECTION
OIL SATURATION, %

FIG. 14 — DYNAMIC CAPILLARY PRESSURE CURVES.

Saturation Distribution — Dynamic

In order to measure accurately effective permeabilities during multiphase flow studies it is necessary to attain uniformity of saturation throughout the test section of the core sample. It has been widely believed that the saturation distribution would not be uniform during dynamic two-phase flow of oil and water because of end effects. These effects may be very pronounced during brine desaturation, but as pointed out by Caudle, Slobod and Brownscombe,[11] when oil is displaced by water the end effect is small in the dynamic method. The results of saturation distribution flow studies on core B are shown in Figs. 11 and 12. The greatest variation in saturation between the two pressure taps was four per cent, and this variation occurred at residual oil. It is probably more difficult to attain uniformity in saturation at or close to residual oil because the oil phase tends to lose continuity. The results show that there was no appreciable accumulation of water at the exit end of the core as might have been predicted from the fact that oil and water were emerging at the same outlet pressure. It should be noted that brine desaturation was started from residual oil (Fig. 12), and in our experience the end effect is not as pronounced as when desaturation is started from 100 per cent brine. After completing the saturation cycle from maximum oil to residual oil and back to maximum oil during two-phase flow of oil and water, two-phase flow of oil and gas at constant interstitial water was studied from maximum oil to residual oil. The saturation distributions during these flow studies are presented in Fig. 13. The greatest varia-

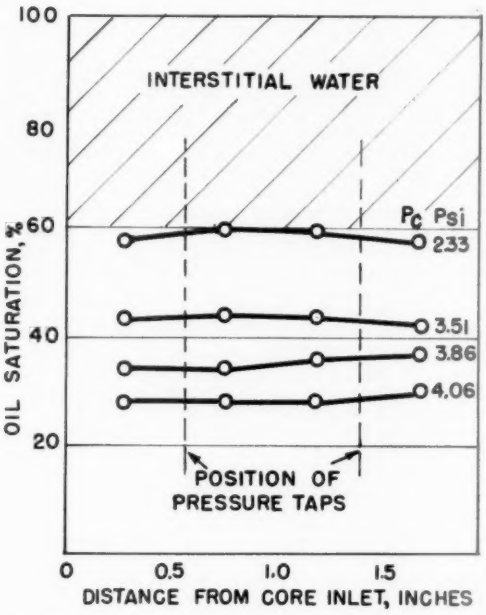


FIG. 15 — SATURATION PROFILES DURING CAPILLARY DESATURATION WITH GAS OF CORE C.

tion in saturation in the test section during oil and gas flow was three per cent, which may have resulted from a slight accumulation of water at the outlet end of the core. Thus it can be seen that it is possible to attain fairly uniform saturation distributions during dynamic flow studies.

Any variation in the saturation distribution directly affects the pressure drops in the flowing phases. In most of the oil and water flow studies reported herein, pressures and pressure drops were measured in each phase separately by means of water-wet diaphragms and open holes. If the saturation distribution were completely uniform throughout the core, the pressure drops in each phase should be identical. In all of the oil and water flow studies in which the pressure drops were measured separately in each phase only a slight variation in the measured readings was obtained at any steady state of flow. Core C was mounted with oil-wet side diaphragms and open holes as pressure taps to permit the measurement of pressure drops in the gas and oil phases separately. Again only a slight difference was found in the measured readings in the two flowing phases, which could be attributed to some variation in the saturation distribution. End effects are less important in dynamic flow systems than might be expected from static capillary pressure curves because the pressure differences between the flowing phases are small. In Fig. 14, dynamic capillary pressure curves for cores B and C are shown. In the first core the pressure difference between oil and water was determined during the saturation change from maximum oil to residual oil, and in this example the oil is, in effect, the wetting phase since it exists at a lower pressure than the water. This phenomenon may be related to hysteresis of the contact angle, and does not necessarily mean that the core material has changed in wettability properties. For core C, Fig. 14, the pressure difference between gas and oil at interstitial water was also determined in the direction of oil production. In this example the gas as expected performed as the non-wetting phase and existed at a slightly higher pressure than did the oil phase. The data support the conclusion that it is possible to attain uniformity of saturation during dynamic multiphase flow studies when the determinations are made across a test section in the center of the core.

Saturation Distribution — Capillary

Measurement of the saturation profile was advantageous in the capillary method in determining when the cores had come to capillary equilibrium. The saturation profiles were found to be quite uniform during desaturation, as was previously

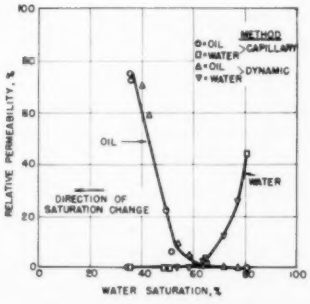


FIG. 16 — COMPARISON BETWEEN CAPILLARY AND DYNAMIC RELATIVE PERMEABILITY METHODS, CORE A.

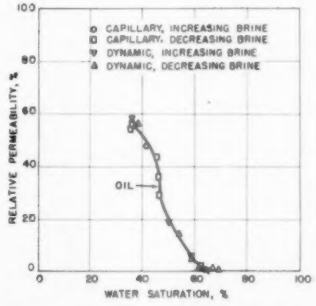


FIG. 17 — RELATIVE PERMEABILITY TO OIL BY DYNAMIC AND CAPILLARY METHODS, CORE B.

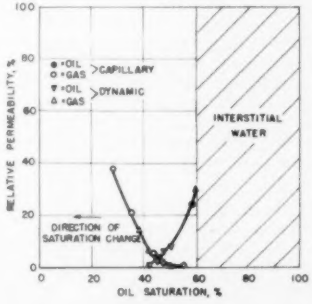


FIG. 18 — COMPARISON BETWEEN CAPILLARY AND DYNAMIC RELATIVE PERMEABILITY METHODS, CORE C.

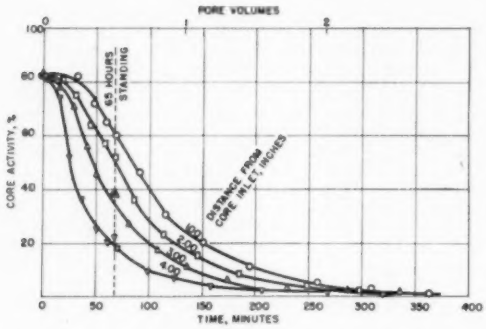


FIG. 19 — DECREASE IN ACTIVITY ON FLUSHING OF CORE D WITH INACTIVE BRINE.

shown by Morgan, McDowell and Doty[4] for the oil-water system. Repeated desaturations of flooded cores starting from residual oil resulted in uniform profiles. In Fig. 15 data are presented for core C showing that saturation uniformity is also readily achieved during capillary desaturation of oil with gas.

Imbibition of water by cores which had been placed in the restored state was found in many cases to be exceedingly slow. In addition, the brine saturation was usually highest in the region near the core entrance. It is conceivable that if sufficient time were allowed, however, uniform saturation profiles might be obtained. It was concluded that because of the excessive time required, use of the capillary method is generally not practical for the oil-water system in the direction of increasing water saturations, although oil-water data need to be taken in that direction to reproduce reservoir conditions. It appears that data taken during a first desaturation from 100 per cent brine to interstitial water would not be pertinent.

Comparison Between the Dynamic and Capillary Methods

Osoba, Richardson, Kerver, Hafford and Blair[5] made a comprehensive comparison of methods of relative permeability determination and found general agreement. However, it seemed desirable to supplement their work with a few experiments in which saturation and saturation uniformity were checked in the course of the measurements. An attempt was made to keep the method of saturation change the only variable.

Figs. 16, 17 and 18 show relative permeability curves obtained on each of three cores (A, B, and C) by both the dynamic and capillary methods. In each case the capillary method curves were obtained first, reducing the core to the restored state condition as the final step. Dynamic method curves were then obtained by introducing both phases to the inlet Aloxite distribution plate. Typical saturation profiles observed in this study have already been presented (Figs. 11, 12, 13 and 15). Oil-water relative permeability data are shown in Fig. 16 for the direction of increasing oil saturation only. The capillary method was impractical in this case for measuring permeabilities in the direction of increasing brine, because imbibition did not occur at an acceptable rate. Therefore, it was water flooded to residual oil, and capillary method data were taken during a second brine desaturation. It seemed appropriate to compare these data with data taken by the dynamic method during a similar cycle. Results of the dynamic method studies for both directions of saturation changes have already been given (Fig. 9). It was noted that during dynamic displacement in the direction of increasing water saturation, the pressure in the water-phase exceeded that in the oil-phase. The fact that relative permeability curves can be measured rapidly by the dynamic method but not by the capillary method in the direction of increasing water saturation can be explained by these pressure differences. In other words, the saturation change is forced when the dynamic method is used.

Comparisons made with a short core (core B) are presented in Fig. 17. Data are shown for both directions of saturation change; however, only one point was obtained by the capillary method in the direction of increasing brine saturation. The effective brine permeabilities of this core were too low to permit any valid comparison.

Oil and gas relative permeability data determined by the dynamic and capillary methods (core C) are compared in Fig. 18.

Data obtained by the two methods are in substantial agreement. Because of a diaphragm failure on core C it was not possible to obtain, by the capillary method, as many points on the oil curve as would have been desired; a comparison of the data obtained by these two methods is of particular interest since it represents the only discrepancy for different methods reported by Osoba, Richardson, Kerver, Hafford and Blair.[5]

Mobility of Brine

Russell, Morgan and Muskat[1] reported experiments indicating a high degree of mobility of interstitial water, but it was pointed out that diffusion might have played a part. Data

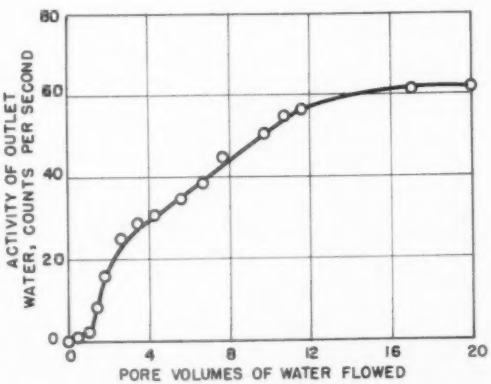


FIG. 20 — SORPTION OF RADIOACTIVE CESIUM FROM WATER FLOWED THROUGH SNOW FLOSS DIAPHRAGM.

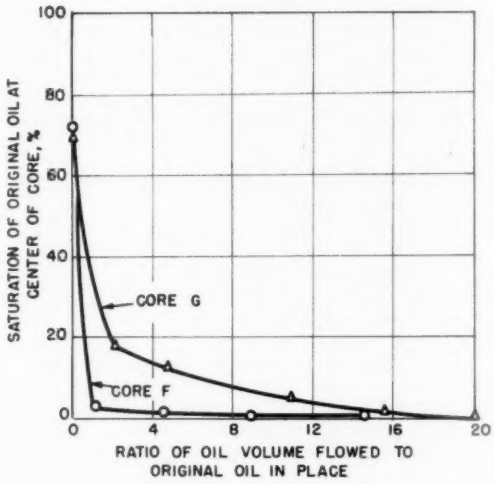


FIG. 21 — REPLACEMENT OF OIL BY FRESH OIL IN RESTORED STATE CORES F AND G.

on an Alundum core (core D) are presented in Fig. 19 confirming these results and indicating that diffusion played no significant part. In these tests core D, containing radioactive cesium in the brine phase was flooded with inactive brine. The decrease in activity at four key positions symmetrically placed along the core is shown. After flow of less than three pore volumes the activity was less than one per cent of the 100 per cent brine saturation value. After 68 minutes of flow, the core was allowed to stand 65 hours. On resumption of flow the activity-time curves continued without break. Diffusion would proceed during standing as well as during flow, and had any appreciable diffusion taken place resumption of flow should have caused a sudden drop in activity.

In the mobility test on Alundum core E, difficulty was encountered in flushing out the cesium 134. Even after 30 pore volumes of inactive brine had been flowed, the activity of the core remained 32 per cent of the original value, varying from 22 per cent at the inlet to 42 per cent at the outlet. This core had Snow Floss diaphragms at both ends; however, flushing through the open holes was also ineffective. Accordingly, a supplementary test was conducted in which a three per cent sodium chloride solution containing a tracer amount of cesium chloride was flowed through two Snow Floss diaphragms which were mounted in Lucite with an Aloxite disk between them. The brine which flowed out of the Snow Floss diaphragms passed through a counting cell, and the radioactivities of various portions were determined until the activity of the outgoing brine equaled the activity of the original brine solution. These results are plotted in Fig. 20, and they show that the radioactivity of the outgoing brine solution continued to increase until about 17 pore volumes had been flowed through the diaphragms. This study definitely demonstrates that Snow Floss diaphragms do not allow passage of cesium ions until a certain quantity has been sorbed in the Snow Floss. Distilled water was then flowed in the opposite direction through the diaphragms until the radioactivity of the effluent was zero. It was necessary to flow about 30 pore volumes before reaching zero activity, and even then the activity of the mounted diaphragms remained quite high. Investigators should be alert to the possibility that sorption of ions in diaphragms might complicate flow studies in cores in which diaphragms are incorporated as part of the system.

Mobility of the Oil Phase

In some of the experiments reported herein, cores in the restored state were saturated with labeled oil by flowing the oil until it had completely replaced the unlabeled oil. The quantities of fresh oil necessary to remove the oil in place in an Alundum core (F) and in a natural core (G) are shown in Fig. 21. The difference in the required volumes of fresh oil in the two cores is probably directly related to the size distribution of the pores occupied by oil. The experimental results show that it takes about twice as much fresh oil to remove the oil in place in core G as compared to that for core F at maximum oil saturations. The effect of pore size distribution on the efficiency of replacement of oil can be more clearly noted in Fig. 22. In this example the oil saturation of core G was reduced to residual oil by flowing gas. It may be inferred that at this saturation the size distribution of the pores occupied by oil was probably much narrower than in the previous example at maximum oil and interstitial water saturation because the gas had displaced the oil from the larger pores. Fig. 22 shows that it was possible to remove all of the oil in place by flowing only about one-twentieth as large a volume of oil as required at maximum oil. The mech-

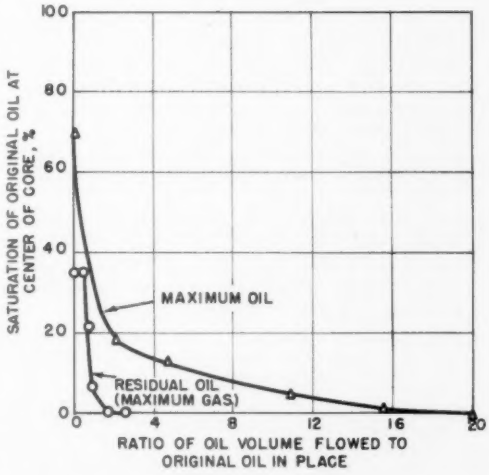


FIG. 22 — REPLACEMENT OF OIL BY FRESH OIL IN CORE G AT TWO SATURATIONS.

anism of displacement of fluids in pores is very important and deserves careful consideration in flow studies. The results obtained indicate that all of the oil in an oil sand is mobile, but that the degree of mobility depends on the size distribution of the pores occupied by oil, which in turn is dependent on the previous history.

CONCLUSIONS

1. An improved method of determining core saturation by means of radioactivity has been developed.

2. Iodo^{131}benzene was demonstrated to be a suitable oil phase tracer.

3. That the radioactive tracer method is well adapted to the study of the mobility of the fluid phases has been established. Oil phase mobility has been found to vary greatly. This is believed to depend on the size distribution of pores occupied by the oil.

4. The dynamic displacement method, as employed in this work, has been shown to be a suitable method of relative permeability determination, giving uniform saturation and uniform pressure drops in the separate phases. The dynamic displacement method is to be preferred over the capillary method for the oil-water system since uniform profiles can be more easily attained as the water saturation is increased from the restored state condition. The greater rapidity and simplicity of the method are attractive.

ACKNOWLEDGMENTS

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APPENDIX A

Preparation of Iodo^{131}benzene

Benzenediazonium chloride solution was prepared according to the procedure of Lucas and Kennedy[19] in a 200 ml three-necked flask using 1/50 of all given quantities. One hundred ml of solution was obtained and stored at 0°F for use as needed.

The sodium iodide was received from Oak Ridge in a concentration of about 20 millicuries/ml. A quantity of 25 or 50 millicuries was generally employed. The iodine was carrier-free and the calculated weight was less than one-millionth of a gram; about 30 mg of solid potassium iodide was added as carrier. A volume of concentrated hydrochloric acid equal to one-fourth the volume of active solution was added, the reaction being carried out in the bottle received. One ml of the benzenediazonium chloride solution was added, the mixture agitated gently, and let stand overnight. The diazo solution was kept cold, but it was found unnecessary to cool the iodide solution, at least not when the volume was less than two ml.

The iodobenzene was extracted with the oil to be labeled. It does not dissolve as readily as might be expected. The contents of the small shipping bottle were rinsed into an eight-oz. bottle with four 5-ml portions of oil and one 5-ml portion of water, and then the large bottle was rolled for one hour. The water layer was separated, and free iodine removed by washing the oil solution with 10 ml of five per cent sodium bisulfite solution, agitating until all purple color was removed from the oil. The sulfite solution was drawn off and the oil diluted to the desired volume. Nearly always over 90 per cent of the activity received was found to be in the oil phase. ★ ★ ★

ENGINEERING STUDY OF THE COOK RANCH FIELD, SHACKELFORD COUNTY, TEXAS

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ABSTRACT

The Cook Ranch Field produces from a very permeable lens of Cook Sand of lower Permian or upper Pennsylvanian age, occurring at an average depth of 1,300 ft. The field was discovered in 1926, and has been operated with low pressure gas injection since July, 1927, one of the first such projects in Texas. Cumulative recovery to Dec. 31, 1950, was 14,701,131 bbl of crude oil, an average of 1,013 bbl per acre-ft of oil section, and 72.5 per cent of the oil originally in place. Analysis of the reservoir performance indicates that gravity drainage has been an important factor in the producing mechanism. The high permeability and uniformity of the reservoir were extremely favorable for this type of operation.

INTRODUCTION

The Cook Ranch Field is the largest of a number of relatively small, shallow producing areas near Albany, in Shackelford County, Texas. This field is one of the first to be operated by gas injection in Texas, and probably is the most successful low pressure gas injection project ever attempted. The field is owned entirely by Roeser and Pendleton, Inc., and Continental Oil Co., and has been operated by Roeser and Pendleton, Inc., since it was discovered. This study has been made possible through the cooperation of Roeser and Pendleton, Inc., in making available a remarkably complete set of records covering all phases of their operations. The purpose of this paper is to present a summary of the history of the operations through Dec. 31, 1950, and to analyze some of the factors which appear to be responsible for the success of the project. Information concerning the physical plant and the early gas injection history has been presented in an earlier paper.[1]

RESERVOIR CHARACTERISTICS

Production in the Cook Ranch Field is from a large lens of Cook Sand, of lower Permian or upper Pennsylvanian age, occurring at an average depth of 1,300 ft. The average dip of the sand body, as shown in Fig. 1, is only about 50 ft per mile to the northwest. The reservoir has an area of 950 acres and contains 15,512 acre-ft of sand, consisting of about 14,512 acre-ft of productive oil zone, and an estimated 1,000 acre-ft of primary gas-cap. The isopachous map (Fig. 2) was prepared from drillers' logs. Recent coring in the field has proven these logs to be quite accurate. The productive limits of the field are defined by shale on all sides but the southwest where a small zone of edgewater was encountered. This water does not appear to have encroached into the reservoir, and water production has been small. A smaller producing area to the south of the Cook Ranch Field also produces from the Cook Sand, but is separated from the reservoir under consideration by a band of shale.

The sand consists of well sorted, coarse grained, rounded and subangular quartz fragments, very poorly cemented. The analysis of 46 chip-core samples from two recently completed test wells indicates a range of porosity values between 12.5 and 28.2 per cent, with an arithmetic average of 24.0 per cent. Air permeability values range between 50 and 2,300 md, with an arithmetic average of 1,200 md. The reservoir where cored is a solid sand body, with no discernible major shale breaks or impermeable streaks. Vertical permeability appears to be of the same magnitude as the horizontal permeability. A core of the Cook Sand was cut in the smaller field to the south, using lubricating oil as drilling fluid. The connate water content of the sand in this core was found to average about ten per cent, and the porosity and permeability were comparable with the values reported above.

No analysis was made of subsurface or recombined hydrocarbon samples,

[1] References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 18, 1951. Paper presented at the Petroleum Branch Fall Meetings in Oklahoma City, Okla., Oct. 3-5, 1951, and in Los Angeles, Calif., Oct. 25-26, 1951.

and no bottom-hole pressure measurements were made. The original API gravity of the produced oil averaged about 39°, and currently is about 37°. The early production records suggest a solution GOR of about 400 cu ft per bbl. The cumulative net produced GOR on Dec. 31, 1950, was 396 cu ft per bbl. The original formation volume factor is assumed to have been about 1.20, and now is approximately 1.05. The initial stock-tank oil content of the reservoir is calculated to have been 20,273,264 bbl, or 1,397 bbl per acre-ft.

HISTORY OF DEVELOPMENT

The field was discovered Feb. 19, 1926, with the completion of the Roeser and Pendleton, Inc.-Marland Oil Co. W. I. Cook "A" No. 1, in Section 85. This well was completed at a total depth of 1,242 ft for an initial flowing production of 1,000 B/D of 39° API oil, after penetrating only one ft of the Cook Sand. The development of the field was rapid, and by the end of 1929, 213 wells had been completed. The peak oil production was reached in December, 1926, when the total monthly oil production was 264,785 bbl from 112 wells. A natural gasoline plant of the absorption type was installed and placed in operation in September, 1926, to serve the Cook Ranch Field and sev-

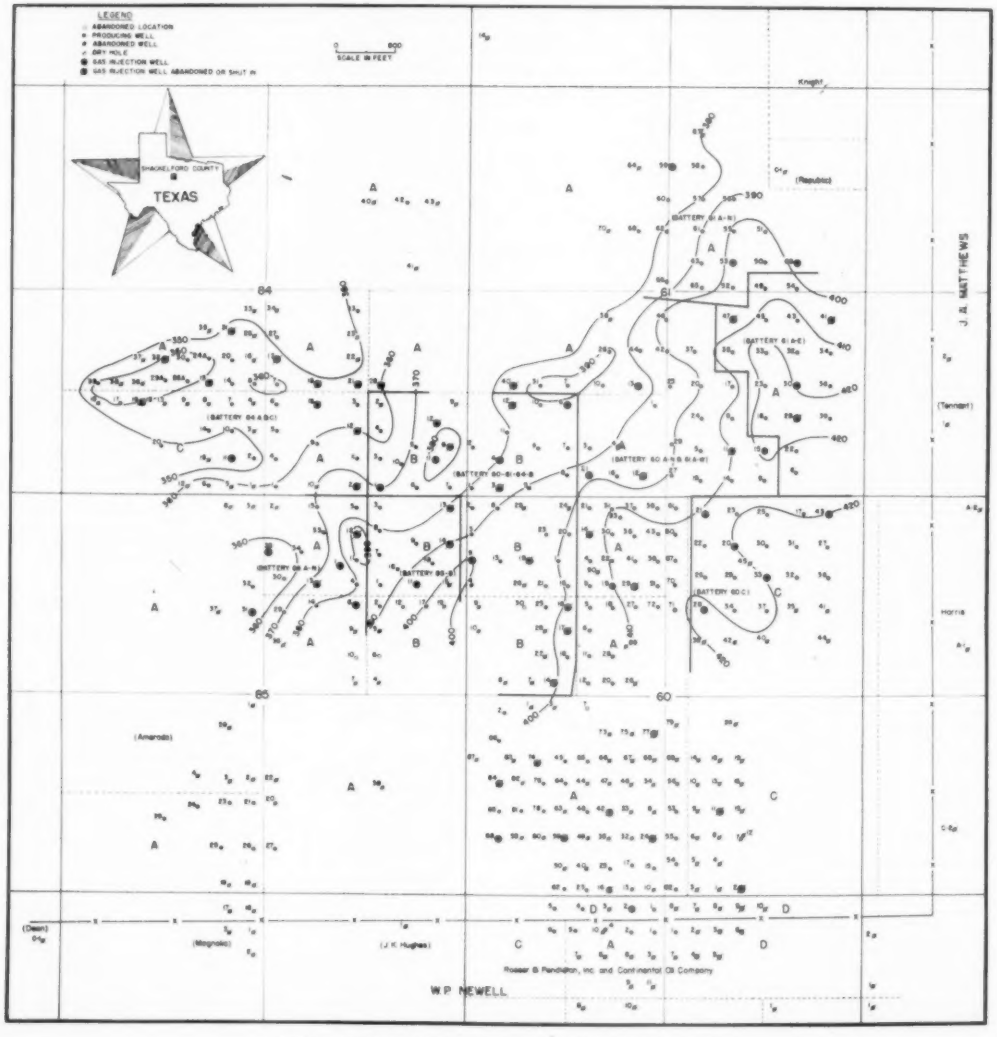

FIG. 1 — STRUCTURAL CONTOUR MAP OF TOP OF COOK SAND.

eral smaller nearby fields. After successful experiments with a portable compressor, facilities were installed in the gasoline plant for compressing fractionator vapors and residue gas at pressures up to 400 psi, and gas injection was started July 15, 1927.

The operators realized the importance to the success of the project of maintaining a complete set of records on all phases of the operation, and set up special gauging and metering facilities for this purpose. As originally developed, the field was divided into 12 tank battery areas, numbered according to lease ownership and location. Each battery area was provided with equipment to measure continuously the produced gas and oil from the area. A small test tank and trap also were installed in each area to enable frequent periodic tests to be made of each well. A system of well test files and production graphs was set up in order to use the information in observing the reservoir performance.[3] Several of the batteries have been combined from time to time for economical operation; eight batteries were in operation on Dec. 31, 1950.

The unit type of operation of the field has permitted more flexible operating conditions than otherwise could be

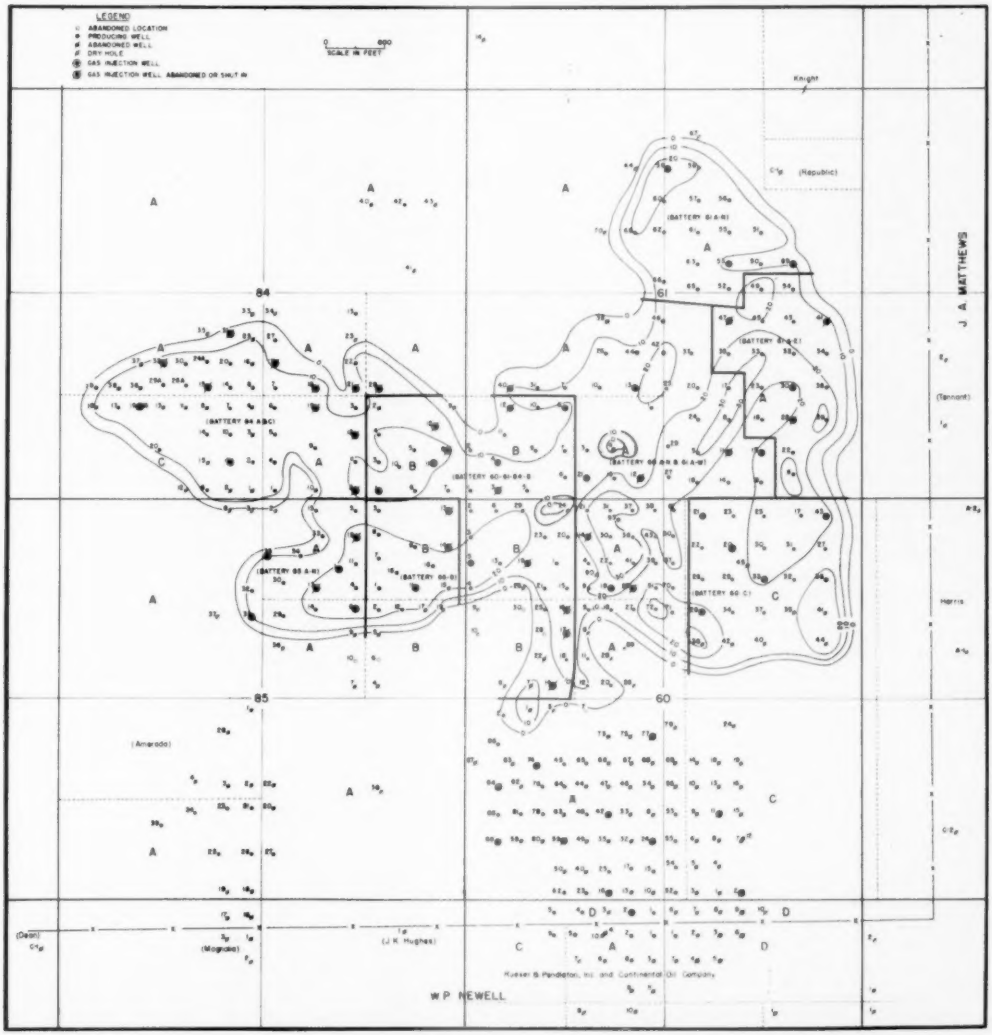

FIG. 2 — ISOPACHOUS MAP OF COOK SAND.

achieved. The operator thereby was enabled to inject gas at the most advantageous locations, and to effect a substantial control of producing gas/oil ratios by shutting in wells where desired. The number and location of gas injection wells have changed from time to time, as dictated by well performance and gas supply. A total of 56 wells have been used for injection, not over 29 of which were operated simultaneously. Cumulative injection volumes for individual wells range from one million to 1.4 billion cu ft of gas. Wellhead injection pressures are not available; pressures at the plant have been maintained at between 250 and 375 psi.

RESERVOIR PERFORMANCE

Table I is a summary of the production and gas injection statistics through Dec. 31, 1950. The cumulative oil production is 14,701,131 bbl, an average of 15,475 bbl per acre or 1,013 bbl per acre-ft of productive oil section. A total of 46,558,446 gal of natural gasoline has been recovered from the produced gas, making a total liquid product recovery of 15,809,665 bbl. The cumulative volume of injected gas is 27,481,295 Mcf, averaging 1,772 Mcf per acre-ft of gross sand.

The performance of the entire reservoir is shown graphically in Fig. 3. With unrestricted production and a rapid development program under way, the oil production increased rapidly during 1926 to a peak of nearly 265,000 bbl for December of that year. In the early part of 1927, unsettled market conditions prevailed which necessitated a short period of voluntary proration between May and November, 1927. No wells were completed during that time, although a number of wells were drilled to the top of the sand and were allowed to remain uncompleted until the latter part of 1928. The rapid decline during most of 1927 evidently was not all due to proration, however, as a decline was evidenced before proration began. Gas/oil ratios exceeded 5,000 cu ft per bbl during the latter half of 1927 at Battery 85B (Fig. 11) and Battery 85A-N (Fig. 10). Gas injection was started July 15, 1927. During the latter part of 1927 and throughout 1928 and 1929, an average of less than half of the produced gas was injected, and 90 new wells were completed. As a result of these factors, the oil production exceeded 157,000 bbl in March, 1927, after which a high decline rate again was established. A second period of proration began Jan. 23, 1930, and continued through 1931. It is difficult to estimate the effect of the injected gas on the oil production rate during 1928 and 1929, but it is significant that the shapes of the oil production and injected gas curves are very similar. It seems probable that the injection of only a relatively small volume of gas during the early productive life of this highly permeable reservoir stimulated the production rate substantially. Throughout 1930 and 1931, the volume

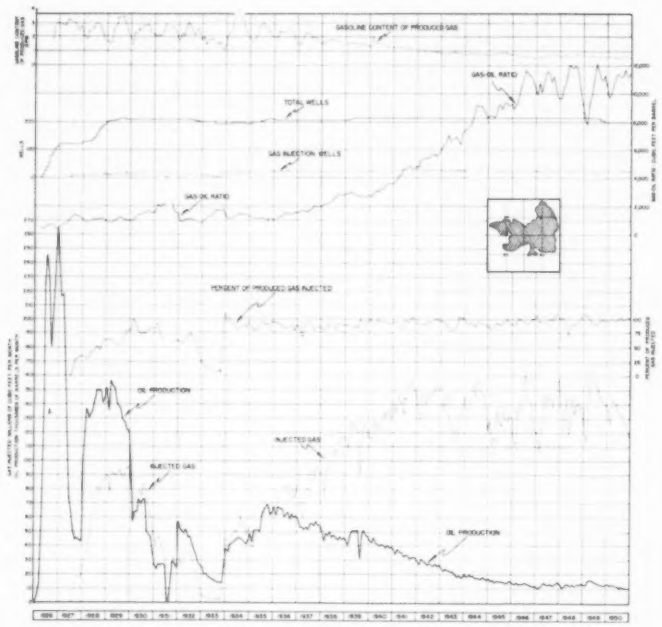

FIG. 3 — RESERVOIR PERFORMANCE, COOK RANCH FIELD.

Table I — Summary of Operations to December 31, 1950

Battery	Productive Area Acres	Reservoir Volume Acre-Ft.	Cumulative Production: Gas Mcf	Oil Barrels	Natural Gasoline Gallons	Oil Recovery Bbl./Acre	Oil Recovery Bbl./Acre-Ft. (Oil Zone)	Gas Injected Mcf	Gas Injected Mcf/Acre-Ft	Cumulative Produced Gas-Oil Ratio	Cumulative Net Produced Gas-Oil Ratio	Cumulative Produced Gas Injected Per Cent
60A-N and 61A-W	232.7	4,112.1	7,129,399	3,722,464		15,997		5,452,260	1,326	1,915		76.5
60C-N	107.2	2,102.3	2,630,551	696,617		6,498		2,770,358	1,318	3,776		105.3
60-61-84B	154.8	2,286.1	6,075,689	2,372,539		14,215		5,146,891	2,251	2,561		84.7
61A-N	87.9	1,213.3	4,673,908	1,474,376		16,773		3,017,302	2,487	3,170		64.6
61A-E	90.0	1,717.0	3,285,660	1,757,814		19,531		3,471,071	2,022	1,869		105.6
84A and C	168.5	2,323.2	3,185,757	1,826,546		11,679		2,678,762	1,262	1,744		84.1
85A-N	59.8	939.6	3,327,615	1,447,265		24,202		3,525,036	3,752	2,299		105.9
85B	49.1	1,018.4	2,990,470	1,403,470		28,584		1,419,615	1,394	2,131		47.5
Total Field	950.0	15,512.0*	33,299,049	14,701,131	46,558,446	15,475	1,013	27,481,295	1,772	2,265	396	82.5

*Oil Section: 14,512
Gas Cap: 1,000

FIG. 4 — RESERVOIR PERFORMANCE, BATTERY 60A-N AND 61A-W.

of gas injected decreased as successive cuts were made in the allowable production, but a higher percentage of the produced gas was being returned to the reservoir. The shapes of the oil production and injected gas curves are remarkably similar during this period. Following the complete shutdown during July and August, 1931, gas injection again was started, and the oil production rate was increased after proration was terminated in January, 1932. During the latter part of 1932, the supply of residue gas available for injection decreased rapidly, and the oil production rate declined at about the same rate. In November, 1933, arrangements were made to purchase dry gas from another area, and the injection rate was stepped up greatly. The similarity between the oil production and injection rate was decreased, and the is striking, and it is believed that substantially all of the oil production after this date is attributable to the gas injection operations. Following this date the volume of gas injected has been maintained approximately equal to the volume produced.

It is interesting to note that the produced GOR increased gradually during the first half of 1927 as the oil production declined rapidly, which would be expected of solution gas-drive depletions. Following the injection of gas, however, the produced GOR declined and remained at about 1,000 cu ft per bbl until 1930 and 1931, when the gas injection rate was decreased, and the GOR increased to about 2,000. This cycle was repeated between 1932 and 1933, when gas injection was curtailed because of a diminishing gas supply. In the early part of 1936, however, the produced GOR started to increase again, and the upward trend has been consistent since that time.

The produced gas enrichment curve shows the characteristic seasonal variations through 1935, but the average enrichment declined perceptibly during 1936 and continued to decrease steadily to about 0.5 GPM in 1950, as increasingly large quantities of dry gas were cycled through the reservoir.

Battery 60A-N and 61A-W is the largest of the eight producing areas in the field, and was formed by combining two batteries in 1935. The southern half of the area was developed largely in 1926 and early in 1928; the northern half was developed in the latter part of 1928 and during 1929. The difference in the magnitude of flush production of each area is readily apparent in Fig. 4. The average initial potential of wells in the southern half was 387 B/D; in the northern half the average initial potential was 94 B/D, which may indicate poorer sand conditions or significant drainage from that area before it was drilled. The oil production curve shown closely parallels the injected gas curve, especially from 1930 on. No explanation is suggested for the increase in oil production and the corresponding decrease in GOR in 1948 and 1949.

Battery 60C-N (Fig. 5) is located structurally in the highest part of the field, and the reservoir in this area contained a primary gas-cap which appears to have occupied about half of the reservoir volume served by this battery. The initial potentials of the wells in this area were generally lower than in the offsetting batteries, and the gas/oil ratios were higher. Nine of the wells, drilled in September and October, 1928, were shut in before the end of the year because of low oil production and gas/oil ratios in excess of 3,000 cu ft per bbl. The cumulative oil recovery from this battery to December 31, 1950, was only 6,498 bbl per acre. This low recovery is largely attributable to the presence of only a thin oil section in this battery, but also may have been partially the result of drainage before the area was drilled.

Battery 60-61-84B was formed by the successive combination of three of the original batteries during 1929 and 1950. The performance curves of this area (Fig. 6) are similar in most respects to those of the entire field shown in Fig. 3. The GOR of this battery also was affected favorably by the gas injection prior to the time of major gas breakthrough in 1936. After 1936, however, the GOR increased rapidly to the current average of about 30,000 cu ft per

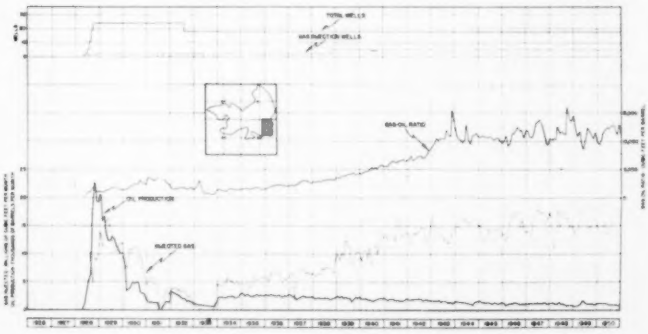

FIG. 5 — RESERVOIR PERFORMANCE, BATTERY 60C-N.

bbl, the highest values for any battery in the field. The portion of this battery lying in Section 60 has produced over 60 per cent of the total oil recovered, and contains about 40 per cent of the total area of the battery.

Battery 61A-N (Fig. 7) was developed during the latter part of 1935, nine years after the field was discovered. This 107.2-acre area has produced 1,474,376 bbl of oil, which indicates that substantial drainage from the area did not occur. Two former gas injection wells, located near the southern edge of this battery, were in operation early in 1930. A cumulative volume of over 260,000 Mcf of gas was injected through those wells between 1930 and the time development started in 1935, which probably minimized the drainage from the Battery 61A-N area. Some of the first wells completed in this area produced initially at very low gas/oil ratios, in the order of 50 cu ft per bbl, but the initial produced GOR of the entire area was not much lower than the other batteries which were developed in 1926 and 1927. Gas injection was started in the battery in 1936, and the oil production rate after the middle of 1936 appears to have been affected materially by the injection operations.

The production histories of Batteries 61A-E (Fig. 8) and 84A&C (Fig. 9) illustrate the effect of reducing the gas injection rate after substantial gas breakthrough has occurred. The injection rates in both areas were reduced when the produced GOR reached about 10,000 cu ft per bbl, with little, if any, apparent effect on the oil production rate. In Battery 61A-E, the average injection rate was reduced only about one-third, with little effect on the GOR trend. In Battery 84A&C, the injection rate was reduced by about two-thirds, which resulted in a substantial immediate reduction in GOR followed by a more gradual rate of increase during the last ten years of operation.

Battery 85A-N (Fig. 10) is the area in which the discovery well of the field is located. This battery was one of the first to be developed, and the peak oil production of 63,712 bbl during June, 1926, was followed by a rapid decline. The produced GOR increased rapidly in July and August, 1927, to a peak value of 5,547 cu ft per bbl, but declined to an average of about 1,100 cu ft per bbl as the rate of gas injection was increased. The oil production rate appears to have been controlled by the injection rate almost as soon as gas injection was started, until 1939. Nine new producing wells were drilled in a westward extension of the field during

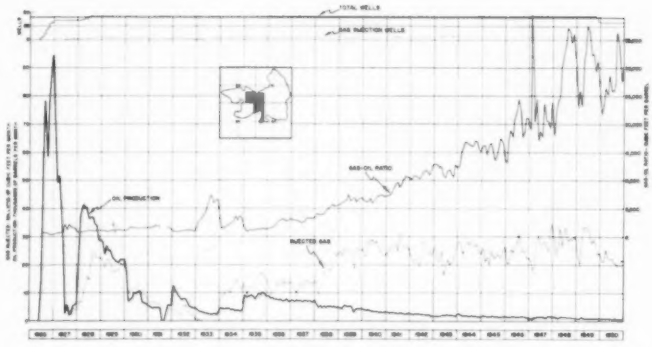

FIG. 6 — RESERVOIR PERFORMANCE, BATTERY 60-61-84B.

FIG. 7 — RESERVOIR PERFORMANCE, BATTERY 61A-N.

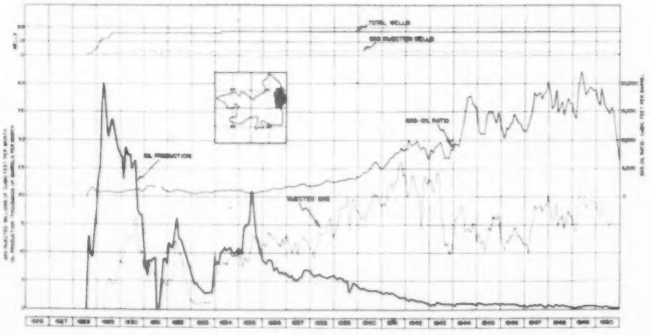

FIG. 8 — RESERVOIR PERFORMANCE, BATTERY 61A-E.

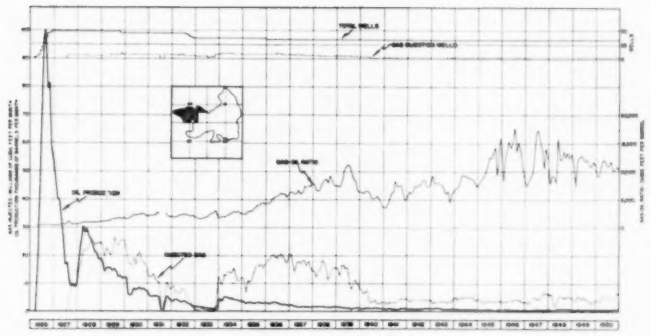

FIG. 9 — RESERVOIR PERFORMANCE, BATTERY 84A AND C.

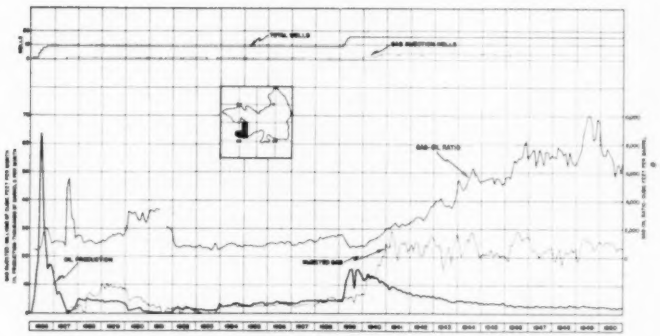

FIG. 10 — RESERVOIR PERFORMANCE, BATTERY 85A-N.

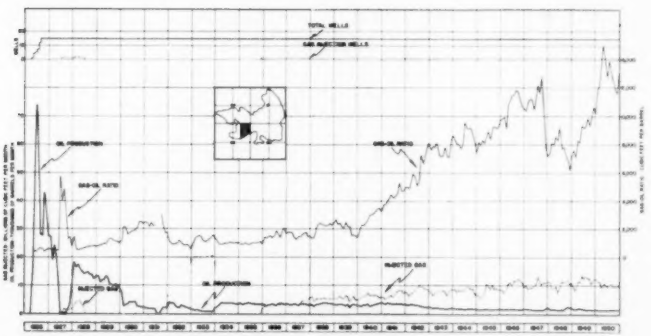

FIG. 11 — RESERVOIR PERFORMANCE, BATTERY 85B.

1939, which caused an immediate increase in oil production. During 1940, the gas injection rate was stepped up and the GOR began to increase rapidly. The effect of the increased gas injection rate on the oil production rate is difficult to determine, and may not have been significant.

Battery 85B (Fig. 11) was developed about the same time as 85A-N, and also sustained an early peak production followed by a rapid decline. The produced GOR increased sharply in June, 1927, and remained above 4,000 cu ft per bbl for three months. Only one well in this area was used for gas injection initially, and the volumes injected were small. Three other nearby wells in offsetting battery areas were used for gas injection beginning in 1927 and 1928, and the operation of these wells undoubtedly contributed to the greatly increased oil production rate early in 1928 and the slow decline rate after gas injection within the battery was stopped. This appears to be confirmed by the increase in production which occurred in early 1934 when supplies of outside gas became available to augment the injection rate. When the injection of gas within the battery was resumed during 1936, two of the three nearby injection wells were shut in, and the sustained oil production rate appears to have been the result of renewed injection within the area.

EVALUATION OF RESULTS

Five test wells have been drilled during the last three years to assist in evaluating the results of the gas injection operations. Well No. 93, in Battery 60A-N and 61A-W, was drilled midway between four old producing wells in November, 1948, and was completed with an initial potential of 23.8 B/D. Well No. 45, in Battery 60C-N, also was drilled between four older wells, and was completed and abandoned in December, 1948, as a dry hole, with an estimated gas potential of 150 Mcf/D. Neither of these wells was cored. Two additional test wells were drilled during August and September, 1951, and one was being drilled as this paper was prepared. The chip-core[3] analysis results from well No. 91 in the southern part of Battery 60A-N and 61A-W, are shown in Table II. It will be noted that the bottom five feet of sand at this well has an average oil saturation of 40 per cent while the upper 27 feet has an average oil saturation of only 18 per cent. This well at last report was pro-

ducing 20 B/D at an average GOR of 5,300 cu ft per bbl. The other test well, in Battery 60-61-84B, was cored through substantially dry sand and was plugged as a dry hole.

An analysis of the reservoir performance curves and the core analysis results indicates that gravity drainage across the bedding plane of the sand body has been a very important factor in the oil recovery mechanism, and is in part responsible for the present high recovery of 72.5 per cent of the oil originally in place. Initially, the movement of the oil displaced by the injected gas probably was substantially horizontal, which would account for the relatively low produced GOR during the first few years of operation. Following the major gas breakthrough, the producing mechanism probably was comparable with the development of a secondary gas cap, with vertical movement of the oil toward the bottom of the section. Some movement of oil down-structure also may have occurred, which could account in part for the higher per acre recovery of Batteries 85A-N and 85B.

Fortunately, the permeability of the reservoir and the uniformity of the sand section permitted great freedom of fluid movement within the reservoir, which enabled the low pressure injection operation to perform so efficiently. It may be concluded that reservoir conditions were extremely favorable for this type of operation.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the management of Roeser and Pendleton, Inc., for permission to utilize their records in preparing this paper, and in particular to G. P. Crutchfield and V. H. Moore for their kind assistance in analyzing the data. He desires also to acknowledge the capable assistance provided by the Reservoir Engineering Section of Continental Oil Co. The author wishes to thank the managements of Roeser and Pendleton, Inc., and Continental Oil Co. for permission to publish this paper.

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2. Wilson, G. M.: "Record System Aids Repressuring Efficiency." *Oil Weekly* (June 15, 1942) **106**, No. 2, 16.
3. May, D. T.: "Chip Coring Technique." *Prod. Monthly*, (Aug. 1948) **12**, No. 10, 30.

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Table II — Chip-Core Data, W. I. Cook Ranch Estate, Well No. 60A-91

Depth Ft	Porosity Per Cent	Air Permeability Md	Core Oil Saturation Per Cent
1,256.1	23.5	420	9
1,257.1	22.5	180	13
1,258.1	21.5	160	20
1,259.0	27.0	710	15
1,260.0	23.9	550	13
1,261.1	23.7	400	35
1,262.2	23.1	740	30
1,263.0	22.9	570	24
1,263.9	15.6	50	39
1,265.0	23.0	1,100	13
1,266.1	24.9	1,650	23
1,267.4	24.9	1,600	25
1,268.6	24.5	1,250	13
1,269.6	24.7	1,400	10
1,270.8	27.1	2,300	14
1,272.0	26.3	1,600	11
1,273.4	25.6	1,900	15
1,274.6	24.0	1,350	11
1,276.3	27.6	1,200	21
1,277.5	24.8	1,100	17
1,278.7	24.8	1,050	19
1,280.0	22.7	650	18
1,281.2	24.6	1,250	13
1,282.5	24.1	1,150	29
1,283.7	24.2	900	32
1,285.0	26.2	1,950	44
1,286.2	27.0	1,100	40
1,287.6	28.1	2,200	44
1,288.7	2.9	0	3

A NEW ADDITIVE FOR CONTROL OF DRILLING MUD FILTRATION

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ABSTRACT

A new synthetic material has been developed which is highly effective in treating drilling muds to reduce filtration rate. The material is the soluble salt of a very high molecular weight condensation product of sulfonated phenol and formaldehyde (SPIF). Laboratory tests show that SPIF is effective in muds of all salinities varying from fresh water to saturated salt water. Alkaline materials, such as soda ash or caustic and quebracho, may be used in combination with SPIF to advantage, and are essential in muds containing saturated salt water. In a field test where the water used in the mud had a salinity of about one-half that of sea water, SPIF in combination with caustic and quebracho made a very satisfactory mud. SPIF does not ferment, but due probably to additional polymerization a slight decrease in effectiveness is found when it is subjected to high pH and high temperature for a long time.

INTRODUCTION

Drilling mud is essential in rotary drilling. The influence of variations in the different properties of a mud on its ability to perform the various functions in drilling of wells is thoroughly understood in some cases and poorly understood in others. For instance, the function of mud density in restraining high pressure fluids is simple and well known. On the other hand, while the value of low filtration is widely recognized, it is seldom possible to determine precisely what filtration rate is required for the mud to perform its functions properly. Filtration rate is important because it influences the ease of moving tools in or out of the hole. Filtration rate also affects the stability of the bore hole walls, which are subject to softening and degradation by aqueous filtrate. Difficulties in rotary drilling are often avoided by using low-filtration muds.

Treatment of fresh-water muds to provide moderately low filtration rates usually consists of adding chemicals to improve the dispersion of the clays. To provide very low filtration rates, organic colloidal materials are added. Among the materials that are used in this way are starch, natural gums, and altered celluloses. In muds that contain large amounts of salt or calcium or magnesium ions, the clays are coagulated and, as a consequence, the filtration rate is undesirably high. In such muds organic colloids are of great importance.

LIMITATIONS OF PRESENT FILTRATION ADDITIVES

Starch and water-soluble gums are widely used as filtration control agents. Starch is the most important material of this kind being used. It has the advantage of relatively low cost. It is effective in promoting low filtration rates, not only in fresh water muds, but also in muds containing large amounts of salts. However, both starch and natural gums are subject to fermentation and must be preserved from damage caused by microbiologic attack. Also, both starch and natural gums tend to increase the mud viscosity undesirably. Furthermore, the quantity of material required may be quite large. This is especially true when substantial amounts of salts are present. In such a case small additions of starch may increase rather than reduce the filtration rate of the mud.

Carboxy-methyl-cellulose, a chemically altered form of cellulose, has some advantages over starch. It is effective in smaller concentrations and does not increase the viscosity as much as

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does starch. However, it is much more expensive than starch and like starch requires a preservative for long, continuous use, although it is subject to microbiological attack somewhat less readily than starch.

Soaps are also used to a considerable extent, usually in combination with oil in emulsion muds. Soap in combination with oil may promote low filtration rates. The addition of soap, however, may increase the mud viscosity greatly, and such soap-emulsion systems are as sensitive to contamination as the clay-water system from which they are prepared.

None of the currently used materials has all the properties desired of a treating agent for control of filtration rate in drilling muds.

NEW SYNTHETIC MUD-TREATING AGENT

In order to develop a material which would have all of the properties desired, a laboratory investigation was initiated. A number of materials were investigated as additives for drilling muds with the objective of discovering a material highly effective at low concentration in reducing filtration rate, especially in salt-water muds, and which would not require preservative and not increase the viscosity greatly. One of the most promising of the materials investigated was a water-soluble, very high molecular weight condensation product of partially sulfonated phenol and formaldehyde. This material has been called SPIF for convenience.

SPIF is a synthetic product made by partially sulfonating phenol with concentrated sulfuric acid and reacting the product with slightly less than an equal molar amount of formaldehyde. The reaction is stopped by neutralization with an alkali when viscosity measurements show that gel formation is about to take place. High molecular weight is necessary for SPIF to be effective; low molecular weight products are useless. The molecular weight is indicated by the viscosity of the solution. A desirable molecular weight is obtained in a viscosity range from 100 to 300 cp at 25°C for solutions containing 30 per cent crude SPIF. The product after neutralization can be dried and powdered for ease of handling. The yield of the crude SPIF is 300 per cent based on the weight of phenol used, and is composed of about 40 per cent active ingredient, 40 per cent salts resulting from neutralization, and 20 per cent low molecular weight polymers.

It is not known just what the cost of manufacturing SPIF in commercial quantities will be. However, the raw material cost is moderate, and the manufacturing steps are simple. It is anticipated that a favorable cost figure will develop. Procedures for preparing SPIF were developed in Humble Oil and Refining Co. laboratories, and manufacture of a quantity sufficient for a field trial was carried out by Monsanto Chemical Co.

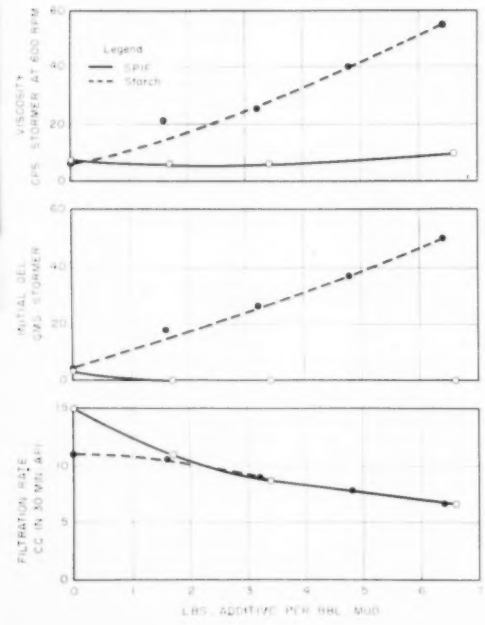

FIG. 1 — EFFECT OF SPIF ON FRESH WATER MUD.

ACTION OF ORGANIC COLLOIDS IN MUD

One theory presumes that organic additives reduce the filtration rate of a mud by plugging the small openings between mineral particles in the filter cake. Any treatment of a mud which diminishes the size of the openings to be plugged, as, for instance, dispersion of clay by chemicals, permits reduction of filtration rates with smaller concentration of organic colloids. Thus, it appears that any of the organic treating agents would be effective in fresh water mud at low concentration because the pores of the filter cake are very small at the beginning of the treatment. However, when substantial amounts of salt or calcium and magnesium ion are present in the mud the clays are coagulated and the pore sizes in the filter cake are much larger. In such muds larger concentrations of the organic colloid are required to give a low filtration rate. In addition, when starch or carboxy-methyl-cellulose is used in such muds the first addition of the agent usually results in higher filtration rates. It is only after the addition of substantial quantities that a desirably low filtration rate is obtained. The absence of a favorable effect from initial additions of starch or CMC is considered to be a result of adsorption of the organic colloid by the mineral solids. There is no evidence that SPIF is adsorbed by mineral solids in either fresh or saline muds since SPIF at low concentrations causes substantial reduction of the filtration rate.

LABORATORY TESTS OF SPIF

The effectiveness of SPIF in synthetic muds of various salt concentrations was tested in the laboratory. Starch, at present the most widely used filtration-control agent, was used as the

basis on which to compare SPIF. The fluid phase of the muds was varied from fresh water to saturated salt water. The following discussions illustrate the results obtained.

Effect of SPIF in Fresh-Water Muds

Fig. 1 shows the effect of the addition of SPIF to a neutral mud composed of 1.6 per cent Bentonite clay, 18 per cent medium-yield clay, and 80.4 per cent fresh water. Included on the chart are comparative data for starch. The effect on viscosity, on initial gel strength, and on the filtration rate is shown for each additive. It is of interest to note that the addition of 6.6 lb/bbl of SPIF decreased the filtration rate from 15 cu cm to 6.6 cu cm API. In comparison, starch in a concentration of 6.4 lb/bbl lowered the filtration rate from 11 cu cm to 6.6 cu cm API. Thus, in a neutral fresh-water mud SPIF is as effective as starch, pound for pound of material, in decreasing the filtration rate. The contrast in the effect of starch and SPIF on the viscosity and initial gel strength of the mud is striking. Addition of starch increased drastically both the viscosity and the initial gel strength, whereas SPIF was almost without influence on these properties.

It should be pointed out that SPIF may be prepared as either the sodium or calcium salt, both forms being water soluble and effective as filtration control agents. It is well known that clays adsorb by base exchange the polyvalent ions such as calcium and at the same time release sodium ions to the solution. As contrasted with clay, SPIF in solution is a completely ionized salt and as such shows no preference for any particular ion. As a consequence, SPIF cannot be expected to remove ions harmful to the mud but, instead, if added as the calcium salt would increase the concentration of the calcium ion in the mud. Thus it is preferable to use the sodium salt of SPIF, especially in fresh-water muds.

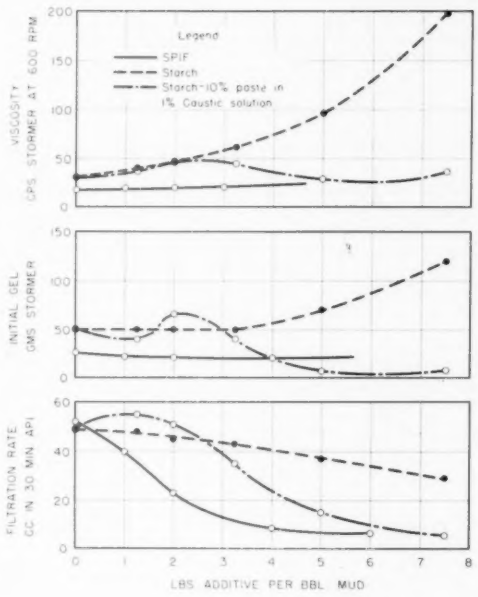

FIG. 2 — EFFECT OF SPIF ON SEA WATER MUDS.

Effect of SPIF in Sea-Water Muds

The effect of SPIF on the filtration rate, viscosity, and gel strength of a neutral sea-water mud composed of five per cent Bentonite clay, 30.1 per cent shale from South Louisiana and 64.9 per cent sea water is shown in Fig. 2. Included on this chart are similar data for starch in a neutral sea-water mud and starch added as a 10 per cent paste in one per cent caustic solution.

In sea-water mud SPIF affected the viscosity and gel strength but little, and reduced the water loss from 52 cu cm to 6.8 cu cm API at a concentration of six lb/bbl of mud. The addition of 7.4 lb/bbl of starch reduced the filtration rate from 49 cu cm to 29 cu cm API, and at the same time the viscosity and gel strength were increased from 32 to 194 cp Stormer at 600 rpm and from 50 to 120 g Stormer, respectively.

It was recognized that the addition of dry starch to a neutral sea-water mud did not entirely simulate well conditions, where higher pH, normally used in conjunction with starch treatment, and heat would aid in the hydration of the starch and render it more effective. Accordingly, the starch was pasted as a 10 per cent slurry in one per cent caustic solution for addition to the mud. The results of the addition of the pasted starch are also shown in Fig. 2. It may be noted that both viscosity and gel strength first increased, passed through a maximum, and then decreased to values well below the original. This decrease of the viscosity and gel strength was caused by dilution by addition of rather large quantities of water with the starch as a 10 per cent paste, and not by any viscosity or gel-treating ability that might be ascribed to the alkaline starch paste. Pasting the starch made it more effective as a filtration-reducing agent. The filtration rate first increased, passed through a maximum, and finally was reduced from the original 49 cu cm to 5.5 cu cm API after addition of 7.4 lb of starch (74 lb of the starch paste) per bbl of mud.

Effect of SPIF in Five Per Cent Salt-Water Mud

A comparison of the influence of SPIF and starch on the properties of a mud in which the fluid phase was composed of five per cent salt water is shown in Fig. 3. In this mud starch caused an increase of the viscosity and gel strength, while SPIF affected these properties but slightly. SPIF proved to be very effective in reducing the filtration rate of this mud in that the water loss was decreased from 30 cu cm to 6.3 cu cm API on addition of 6.4 lb/bbl. When the quantity of SPIF was increased to 13 lb/bbl, the water loss was decreased to four cu cm API. In contrast, starch, on addition of the first four lb/bbl, caused the filtration rate to increase from 33 cu

cm to a maximum of 37 cu cm and then decrease to 34 cu cm API. Further additions of starch caused the filtration rate to decrease so that the water loss was 7.8 cu cm API after the addition of 10 lb/bbl.

Effect of SPIF in Saturated Salt-Water Mud

SPIF in a neutral mud in which the liquid phase was saturated salt water did not cause a significant decrease of the filtration rate and did not affect greatly the viscosity or the gel strength of the mud. In comparison, the first 3.4 lb of starch per bbl mud caused the filtration rate to increase from 54 cu cm to 118 cu cm API. When the starch concentration was increased to 7.4 lb/bbl, the filtration rate was decreased to 17.5 cu cm and on further increase to 11.1 lb/bbl, the water loss was decreased to 5.3 cu cm API. Addition of starch caused viscosity of the saturated salt-water mud to increase in a somewhat erratic manner, increasing from 25 to 175 cp, then decreasing to 122 cp and finally increasing to 162 cp as 11.1 lb of starch per bbl was added. The gel strength was increased from 48 to 75 g Stormer and then decreased to six g, which value did not change further as more starch was added. These data are illustrated in Fig. 4.

It was found that by increasing the alkalinity of the saturated salt-water mud with soda ash or caustic SPIF became effective as a filtration reducer. Illustrated in Fig. 4 is the manner in which SPIF reduced the water loss of a saturated salt-water mud containing four lb of soda ash per bbl. It may be seen that the filtration rate was reduced from 150 cu cm to 27 cu cm, then to 13 cu cm and finally to 6.5 cu cm API, respectively, on addition of four, six, and eight lb of SPIF per bbl of mud. SPIF did not cause any significant change in the viscosity when these additions were made. Thus, if the alkalinity of the mud is increased, SPIF becomes effective as a filtration-control agent in saturated salt-water muds.

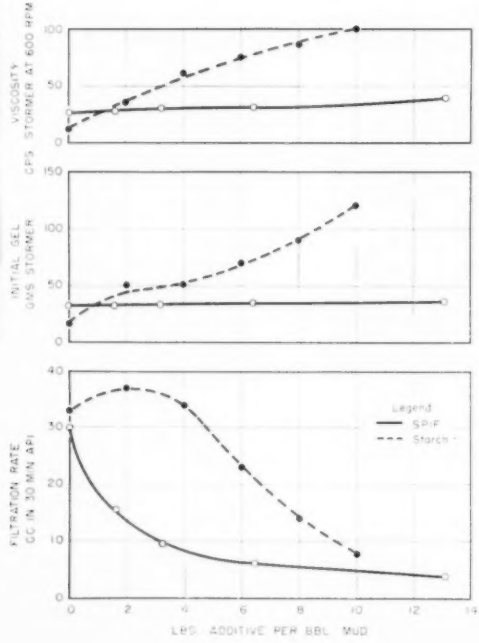

FIG. 3 — EFFECT OF SPIF ON FIVE PER CENT SALT WATER MUDS.

Stability of SPIF

One of the principal difficulties in the use of starch or carboxy-methyl-cellulose for filtration control is their susceptibility to fermentation, which makes necessary the use of a preservative. The use of a preservative in many cases adds considerably to the mud treating costs. SPIF, by virtue of its composition, is immune to microbiological attack. With SPIF there does exist a possibility of certain chemical reactions that could lead to a loss of effectiveness. First, continued polymerization could occur, which might increase the molecular weight to a point where the SPIF is no longer completely soluble. Second, there exists a possibility that a reaction similar to hydrolysis might take place and cause a decreased molecular weight and a decreased efficacy. Other than the reduction of the effect on filtration rate, no products formed would be deleterious to the mud properties.

To test the rate at which SPIF decreases in efficacy with time, a mud was made with sea water and shale taken from a well drilled in South Louisiana. This mud, which had a water loss of 90 cu cm API, was treated with six lb/bbl SPIF to decrease the water loss to 6.8 cu cm API. The treated mud was divided into four aliquots, two of which were adjusted to pH 12.1 with caustic and quebracho solution, and the other two left at pH 8.3. One sample each of pH 8.3 and pH 12.1 was aged at 75°F, and the other samples were aged at 190°F. The results of these tests are summarized in Table I. These data show very little effect on the filtration rate of the mud aged 50 days at pH 8.3 and at 75°F; the water loss increased from 6.8 cu cm to 9.6 cu cm API during this time. When the pH was increased to 12.1 at 75°F or the temperature at either pH was increased to 190°F, the deterioration was increased, the filtration rate increasing from 6.8 cu cm to 23.8 cu cm API in 50 days at pH 12.1 at 75°F. It is of interest to note that both viscosity and gel strength changed but slightly, and in most cases both decreased.

FIELD TEST OF SPIF

To provide a supply of SPIF for a field test in a well, Monsanto Chemical Co. cooperated in the preparation of 22,000 lb of the material. The details for the manufacture were worked out jointly.

The well chosen for the test of SPIF was a 14,000-ft test to be drilled in Lake Raccourci, Louisiana, designated as State Lease 1449, Well 1. This well was chosen for several reasons. First, the location made it advantageous that the relatively salty water, 11,600 ppm chloride, of the Lake Raccourci embayment be used for the mud in order to save tug and barge costs incurred in hauling fresh water. The diesel-electric rig did not require fresh water. Second, the well was to be a deep test and would give an extended time for the test. Third, several other wells had been drilled in the area using the salty water for the mud and standard filtration control materials to reduce water loss which could serve as a basis for comparison of the cost and efficacy of SPIF.

The well was spudded in April 22, 1951, using a mud made from bentonite, lime, and the salt water of the lake. Conductor pipe was set at 228 ft and 13⅜-in. surface pipe was set at 1,817 ft. Chemical treatment was started at 7,030 ft with the addition of caustic quebracho solution. The drill pipe was twisted off at 7,484 ft while drilling in 12¼-in. hole, resulting in a five-day fishing job to recover the drill collars and bit. The first addition of SPIF was made on April 30, 1951, while the fishing operations were in progress. The material was added as a dry powder through a mechanical mud mixer. The addition and mixing were accomplished with no difficulty and after addition of 9,350 lb of SPIF, about 4.7 lb/bbl of mud based on an estimated mud volume of 2,000 bbl, the water loss was reduced from 52 cu cm to 12 cu cm API. Sufficient water had been added to reduce the mud weight from 10.7 to 10.1 lb/gal and the viscosity increased with clay to 37 sec Marsh funnel. The alkalinity was 0.01 per cent and the chloride content was 11,400 ppm.

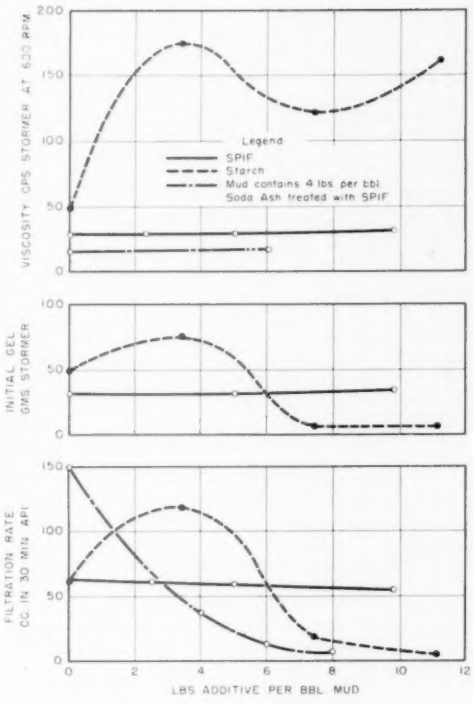

FIG. 4 — EFFECT OF SPIF ON SATURATED SALT WATER MUD.

Table 1 — Aging Tests of SPIF in Sea-Water Mud*

Time, days	pH	Temp., °F	Stormer Viscosity cp	Stormer Initial Gel, g	Filtration cu cm, API
0	8.3	75	6.	2	6.8
0.75			6.	2	7.0
4			5.	3	7.5
11			5.	2	6.5
22			4.5	1	7.5
50			4.5	0	9.6
0	12.1	75	4.5	2	6.4
0.75			5.	0	6.0
4			4.5	0	6.0
11			4.5	0	9.6
22			4.5	0	10.6
50			4.5	0	23.8
0	8.3	190	6.	2	6.8
0.75			4.5	1	6.8
4			4.5	1	7.8
11			4.5	1	8.6
22			4.5	1	11.0
50	Sample lost during aging period				
0	12.1	190	4.5	2	6.4
0.75			4.5	0	6.6
4			4.5	0	9.2
11			4.5	0	10.5
22			4.5	0	15.5
50			6.5	0	18.6

*Mud prepared by stirring shale from a well in South Louisiana into sea water. Initial filtration of 90 cu cm API reduced to 6.8 by treatment with 6 lb/bbl of SPIF. The pH was adjusted in two aliquots from 8.3 to 12.1 using caustic and quebracho solution. pH adjustment decreased filtration rate from 6.8 to 6.4 cu cm API.

After the fish was removed on May 4, 1951, the hole size was reduced to 9⅞ in. and drilling was continued to 9,180 ft. The average mud properties maintained while drilling the 1,700 ft in this interval were: weight, 10.4 lb/gal; viscosity, 37 sec Marsh funnel; chloride, 12,500 ppm; alkalinity, 0.07 per cent; filtration rate, 11.0 cu cm API. Maintenance of the mud in this interval required 3,740 lb of SPIF. Caustic quebracho and caustic lignite solutions were used for viscosity control.

The mud was converted at 9,180 ft to an oil emulsion by addition of diesel oil. After emulsification was complete, the mud weighed 10.4 lb per gal, the viscosity was 51 sec Marsh funnel, chloride content was 13,000 ppm, the alkalinity 0.09 per cent, oil content 14 per cent, and the filtration rate was eight cu cm API.

The 9⅞-in. hole was drilled to 10,450 ft, at which depth drilling was halted, the hole was reamed to 12¼ in. from 7,492 to 8,600 ft, and 9⅝-in. casing was set and cemented at 8,594 ft on May 13, 1951. The average mud properties while drilling the 1,300 ft of hole and reaming were: weight, 10.4 lb/gal; viscosity, 42 sec Marsh funnel; chloride, 14,000 ppm; alka-

linity, 0.09 per cent; oil content, 12 per cent; filtration rate, 8.6 cu cm API. The SPIF required to maintain the filtration rate during this 1,300 ft interval was 1,320 lb.

On May 13, 1951, the cement was drilled from the casing, which caused a slight contamination from the cement. The mud was converted at 10,500 ft to a SPIF-emulsion-lime mud. The filtration rate increase to 23 cu cm API after addition of 2,100 lb of lime. It required 4,620 lb SPIF to lower the water loss to 10 cu cm API. The well was drilled from 10,500 to 12,900 ft, during which time lime was added to the mud, along with caustic quebracho and caustic lignite solutions for viscosity control. The SPIF requirement for this 1,400 ft of hole was 2,530 lb to maintain an average filtration rate of eight cu cm API. The alkalinity was maintained at about 0.25 per cent, and the other properties remained as previously carried.

The supply of SPIF was exhausted at 12,900 ft, making necessary the use of starch for filtration control below this depth. The conversion to starch was made with no difficulty other than an increased viscosity normally experienced when starch is added to a mud.

There were no special treatments required at any time during the SPIF test. The material was easy to handle and to mix with the mud. There was no evidence of deterioration of the SPIF during the 27 days over which the test was conducted.

The maintenance cost, once the initial SPIF treatment had been made, was comparable with the average of three other wells drilled in Lake Raccourci using the lake water for the mud. Although the total mud cost on this job was somewhat more than the average of the three comparison wells, the difference was due to the relatively high cost of the experimental quantity of SPIF. A lower price for the polymer may be anticipated with commercial manufacture, and more experience with SPIF mud treatments should make its use competitive with the filtration control agents now in use.

CONCLUSIONS

The results obtained from laboratory studies and field use of a sulfonated phenol formaldehyde polymer for control of filtration rate of drilling muds have led to the following conclusions:

1. A new synthetic material, SPIF, has been made that will control water loss from drilling mud;

2. The material is suitable for treatment of muds made from fresh water or water that contains salt in concentrations up to saturation;

3. SPIF is not subject to fermentation;

4. SPIF does not increase the viscosity or gel strength of a mud to an undesirable degree;

5. The new filtration control agent requires no special mud treating techniques. ★ ★ ★

The Drift of Things

. . . as followed by **EDWARD H. ROBIE**
Secretary AIME

In the Black

Though the final figures are not available as this is written, it seems certain that the Institute accounts will show $7,000 to $8,000 surplus for the year 1951. This is the first time this has happened since 1941. No money had to be taken from any of the Funds to bring about this happy condition. Furthermore, the amounts allowed for depreciation, bad debts, and inventory adjustments were more liberal than in the past.

Income increased some $29,000 over 1950. Dues received from old members increased moderately, but dues from new members dropped off $2,000 and from initiation fees quite severely — from $17,000 to $11,000. The number of new members did not live up to expectations and a change in procedure caused a delay in getting some of them on the rolls. A large number of the new members paid an installment of $5 on their initiation fee instead of the full $20. Junior Members, of course, pay no initiation fee.

Brightest spot in the income picture was the increase in advertising income — from $103,000 in 1950 to $143,000 in 1951. All three of the journals shared in this, mining being up $18,000; metals, $9,000; and petroleum $13,000. Sales of the journals dropped off slightly, and sales of Transactions volumes more so — from $35,000 in 1950 to $27,000 in 1951, with a further drop of $5,000 accounted for by a change in accounting procedure. On the other hand, sales of other publications increased by $10,000.

Expenditures in 1951 increased by only about $6,000 over 1950, an exceptionally good showing in view of the decrease in the value of the 1935-39 dollar from 58 cents at the end of 1950 to 53 cents at the end of 1951. This decrease means higher prices for the things the Institute has to buy; especially, higher salaries have to be paid for the office help which does the work at Institute headquarters and its branch offices.

A marked saving in publishing costs was made because no directory of members was published in 1951. This cost $19,000 in 1950 but the officer and committee list issued last year cost only $2,000.

Expenses chargeable to technical Divisions and Branches increased from $39,000 in 1950 to $54,000 in 1951, the increase being chiefly in the Mining Branch. One reason was that the expense of the Salt Lake City office was all met out of operating income in 1951, whereas its cost was taken out of income in the Barron Fund in 1950.

Expense for the three journals dropped $11,000. This is quite surprising considering the high quality that was maintained. It shows particular care on the part of the editorial and publishing staffs in condensation and editing of articles, and avoidance of luxurious printing practices. Costs of both the mining and metals journals decreased, but improvement in the petroleum journal increased its cost about $7,000.

Compared with 1950, general and administrative salaries, and accounting and membership department expenses increased from $93,000 to $95,000, a most modest increase in view of the higher salaries that had to be paid. A saving of $8,000 was made in the pension account because of staff changes. Miscellaneous expenses increased $5,000; the allowance for depreciation of equipment, furniture, and fixtures, including adjustment for prior years, accounted for $12,500 added expense; and a reserve was set up of $3,000 for bad debts, an accumulation of some years.

Branchwise, the Petroleum Branch again, as in 1950, operated on practically a balanced budget as between income and expense. The Mining Branch had a surplus of $35,000 compared with $24,000 in 1950; and the Metals Branch decreased its deficit from $42,000 in 1950 to $27,000 in 1951.

Emphasis in 1952 must be made on increasing income in two main directions: Increasing the advertising, and getting more new members. The latter not only adds dues and initiation income, but adds to the circulation of the journals, thus making them better advertising media. In 1950, 21 per cent of the AIME income came from advertising and 63 per cent from dues and initiation; in 1951 the respective figures were 28 per cent and 59 per cent. Contrast these figures with those of a sister society, such as the American Society of Mechanical Engineers for instance, which last year received 41 per cent of its income from advertising and only 40 per cent from dues and initiation fees, even though it has 37,500 members and its dues, for the Member grade, are $25.

By getting more new members and more advertising the expected continued increase in costs due to inflation may be met. Other avenues of income will also be studied. Publication of a directory in 1952 will add a substantial item to costs. On the whole, it seems that a surplus should again be shown in 1952 but it will probably be only a modest one, as it was last year.

It would appear that there is little hope, before 1953, of doing much in the way of rebuilding the Institute's funds available for meeting deficits. They almost reached the vanishing point in 1950.

AIME Fall Meeting in Chicago

Plans have been concluded for the dates and location of the AIME Fall Meeting in Chicago next September. This will be in connection with the Centennial of Engineering celebration, which is to cover the first two weeks of the month. A total of 51 engineering organizations will hold meetings during that fortnight.

AIME technical sessions will be held in the Palmer House on Friday and Saturday, Sept. 5 and 6, with a dinner-dance Saturday night. One or more Divisions that contemplate an extensive program with field trips may add Thursday, Sept. 4, to their meeting dates. Already, the Industrial Minerals Division and the Minerals Beneficiation Division are definitely planning to participate; the Mining, Geology, and Geophysics Division is almost a certainty; and several other Divisions planned to make their decision at the Annual Meeting.

The dates selected will enable those who attend to have Sunday for visiting the Museum of Science and Industry, where many special engineering exhibits will be installed. On Monday and Tuesday following, there will be special convocations on the metals industries, with leading speakers, arranged by the Centennial committee. On Wednesday night there will be a banquet for the entire engineering group, which should attract several thousand people.

It looks as though Chicago should be included in the vacation plans of all engineers in 1952. ★ ★ ★

Personals

RALPH G. GRANT is now personnel manager for the Lane-Wells Co. at Los Angeles. In this capacity, Grant will supervise all head office personnel activities, records, and welfare and activities programs. He will assist the manager, Industrial Relations, in matters concerning salary administration, job conditions and classifications, labor relations, and employee training programs. Grant joined Lane-Wells in 1946 after five years of service in the Army. His previous position was that of subdistrict superintendent at Harvey, La.

+

JOSEPH C. VAUGHN is production research engineer with the Stanolind Oil and Gas Co., Tulsa, Okla. He has been associated with the Quaker State Oil Refining Corp., Bradford, Pa.

+

EDWARD H. CONROY, JR., has joined the Texas Gulf Sulphur Co., Worland, Wyo.

+

RUFUS DUDLEY CHAMPION, JR., is now employed by the Amerada Petroleum Corp., Monument, New Mexico.

+

DON DALE LITTLE, Standard Oil Co. of Calif., is now senior reservoir engineer at San Francisco.

+

RONALD L. ACKLEY has accepted a position with the Standard Oil Co. of California, Taft, Calif., as engineer trainee.

+

JAMES M. BUGBEE, JR., has been transferred to the advertising department of Baroid Sales Division, National Lead Co., Houston, to assist in the preparation of the firm's technical publications relating to oil well drilling muds, well logging, and testing equipment. Educated at the University of Texas, he has been with Baroid since 1947, doing well logging work in the southern half of the United States and mud engineering service in North Central Texas oil fields.

JOHN JOSEPH JUSTEN has joined the field research laboratories of the Magnolia Petroleum Co., Dallas.

+

F. DAVID HART, research and development dept., Socony-Vacuum Laboratories, has been transferred from Whittier, Calif. to Paulsboro, N. J.

+

JOHN R. CHESTNOLVICK, area production engineer for Continental Oil Co., Fort Worth, was promoted to assistant district superintendent of production in Hobbs, N. Mex.

+

JAMES W. ROCKHOLD recently joined the National Cooperative Refinery Association as chief engineer of the production and pipe line divisions, Great Bend, Kans.

+

CLARK M. SHERWOOD is presently employed by the Ohio Oil Co., Casper Division, McFadden, Wyo.

+

JOHN V. PENNINGTON is now director, Drilling Research, Inc., Houston.

+

JAMES DONALD CLARK has resigned from the Union Oil Co. of California, Houston, to accept a position with the Stanolind Oil and Gas Co., Alvin, Tex.

+

WALTER H. DICKINSON, Phillips Petroleum Co., Houston, has been transferred to Casper, Wyo.

+

CLIFFORD L. BUCKINGHAM is with Petroleum Development (Qatar) Ltd., Persian Gulf.

+

V. L. FORSYTH has been named chief engineer of Lane-Wells Co. in Los Angeles, Calif. Formerly assistant chief engineer, Forsyth replaces NORMAN L. DORN, who resigned because of ill health.

+

WALTER E. LONG has become a petroleum geologist for The American Metal Co., Ltd., with offices at 61 Broadway, New York 6, New York. He was recently geologist for Geier-Jackson, Inc., and formerly with Magnolia Petroleum Co.

GEORGE L. RATCLIFFE has been elected a vice-president of National Lead Co., it was recently announced by J. A. Martino, president. Ratcliffe has been a director of National Lead Co. since 1948 and general manager of the Baroid Sales Division of the company since 1929. Ratcliffe joined National Lead in 1929 as president and general manager of the California Talc Co., one of the predecessor companies to Baroid. Prior to this, he also saw service with Standard Oil Co. (N.J.), Texas Pacific Coal and Oil Co. and the General Petroleum Corp.

+

JAMES H. COBBS is now petroleum engineer for the Tide Water Associated Oil Co., Midland, Tex.

+

MORTON T. HIGGS has been elected a vice-president of Lane-Wells Co., according to an announcement by Rodney S. Durkee, president. Higgs has been in the petroleum industry since 1916, spending the first 14 years as a geologist. He was with the Sperry-Sun Well Survey Co. as Gulf Coast regional manager for eight years before joining Lane-Wells as divisional sales manager at Houston in 1938.

Thomas J. Hamilton Dies

Thomas James Hamilton (Member 1939) died Oct. 6, 1951, at Wichita, Kans. Born Aug. 14, 1896, near Warren, Ind., he was a graduate of Ohio State University. He joined the Empire Oil and Gas Co. in Augusta, Kans., in 1914, and became production superintendent for Phillips Petroleum Co. in 1922, serving in various parts of Kansas, Oklahoma and Texas until 1944. After two years with Mayo Properties of Minneapolis, he became chief production engineer for the National Cooperative Refining Association, holding this position until his death. He was a former mid-continent chairman of the API, and at the time of his death was vice-chairman for Wichita of the Kansas Section, AIME.

X-Ray Absorption Method

Continued from Page 15, Section 1

in full agreement with X-ray theory. In the case where the oil or water existed inside the core (Case A) which covers both drainage and imbibition types of flow processes, again the relationship between absorption and saturation (amount of oil in X-ray beam path measured by weighing the core) agrees with X-ray theory for uniform distribution of fluids. This particular porous material does show considerable hysteresis effect in flow behavior and therefore can be considered as suitable for these evaluation tests. The fact that this experimental evidence does not conform to the expectations of Lipson can be explained on the basis of the models used. Lipson's fluid distribution models are applicable to conditions of saturation distribution for a very small group of pores. In practice, a large number of pores influence the absorption of the X-ray beam (approximately 10^6 pores in a $\frac{3}{4}$-in. diameter core plug and an X-ray beam $\frac{1}{8}$ in. x 5/16 in.). The cumulative effect of the multitude of pores involved in the measurement produces essentially a uniform distribution of the fluids as far as the X-ray beam is concerned. Therefore, a direct application of Lipson's theoretical consideration does not describe the relation of fluid saturation and relative X-ray absorption for the case of fluid flow in porous materials. Experimental evidence shows that for the manner in which it is used, relative absorption is uniquely related to fluid saturation in cores.

ACKNOWLEDGMENT

The authors wish to thank the management of Stanolind Oil and Gas Co. for permission to publish this technical note, and to D. R. Parrish for his assistance in making some of the measurements.

REFERENCES

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2. Morgan, F., McDowell, J. M., and Doty, E. C.: "Improvements in the X-Ray Saturation Technique of Studying Fluid Flow," *Trans.* AIME, (1950) **189**, 183.

★ ★ ★

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Replies to the positions coded Y6685, Y6654, Y6653, and Y6296 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

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♦ Petroleum geologists, experienced, for subsurface study. Should have three to five years' experience in geological work. Location, Texas. Y6653.

♦ Mechanical engineer, designer, with two to five years' experience in design and layout for oil refinery. Salary, $6,000 a year. Location, New York, N. Y. Y6296.

★ ★ ★

H. N. Appleton Named AIME Assistant Secretary

At the meeting of the Executive and Finance Committees on Jan. 9, H. Newell Appleton, as head of the newly organized Institute Activities Department, was made an Assistant Secretary of the Institute instead of Assistant to the Secretary, his former title. At the same meeting John V. Beall was appointed Manager of Publications of the Institute to succeed Thomas E. Lloyd whose resignation was effective Feb. 1. Beall will continue as editor of *Mining Engineering*. ★ ★ ★

Proposed for Membership, Petroleum Branch

Total AIME membership on Dec. 31, 1951, was 17,482; in addition, 2,229 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Thomas G. Moore, Chairman; Carroll A. Garner, Vice-Chairman; George B. Carless, F. W. Hanson, Albert J. Phillips, Lloyd C. Gibson, R. D. Mollison, John T. Sherman, Alternates, A. C. Brinker, H. W. Hitzrot, Plato Malozemoff, Ivan Given, T. D. Jones, W. A. Clark, Jr.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend privileges, but does not desire to admit persons unless they are qualified. Objections on applications should be received on the 15th of the month following publication of PETROLEUM TECHNOLOGY.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; A, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

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Silsbee — Lunceford, Major L., Jr. (R,C/S-S-J).
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La Paz — Aldazosa, Jorge (M).

MEXICO

Mexico, D. F. — Frost, Noel (M). ★ ★ ★

Bylaws Changes Proposed On Handling AIME Funds

At the meeting of the AIME Board of Directors on Feb. 17, the Directors signified their intention of amending Art. VIII, Sec. 3, paragraph 3, as follows:

Present wording: "The funds of the Institute shall be paid out by checks signed by the Treasurer and countersigned by the Secretary; in case of absence or disability, the President or any Vice-President may act for the Treasurer, or any Vice-President for the Secretary, but the Treasurer may, at his discretion, place funds of the Institute, not at any time exceeding $2,500, at the disposal of the Secretary's office for the purpose of paying the smaller current expenses of the Institute and may also establish a payroll account. Such funds shall be banked in the name of the Institute, and drawn by checks signed by any two of the following persons: Secretary, Assistant Secretary, Assistant Treasurer, or Office Manager."

To be revised to read: "*The funds of the Institute shall be paid out by checks signed by the Treasurer and countersigned by the Secretary. The Treasurer or Secretary may at any time appoint any officer or employe of the Institute to act for him. In case of absence or disability, the President, any Vice-President, Assistant Treasurer, Assistant Secretary, or Controller may act for the Treasurer and/or the Secretary. The Treasurer may at any time place funds of the Institute not exceeding $10,000 at the disposal of the Secretary's office for the purpose of paying the current expenses of the Institute and may also establish a payroll account. Such funds shall be banked in the name of the Institute and drawn by checks signed by any two of the following persons: Secretary, Assistant Secretary, Assistant Treasurer, Controller, Business Manager, Office Manager.*"

Notice of intention to amend Art. VIII, Sec. 2, paragraph 3, was also given.

Present wording of 6th, 7th, and 8th sentences: "All bills, accounts, salaries, payrolls, and claims of every kind against the Institute shall be examined by the Finance Committee and be approved by at least one member of the Committee. The Committee shall not authorize any payments in excess of appropriations. If at any time any of the appropriations seem in danger of being insufficient, the Finance Committee shall report the same to the Directors."

To be revised to read: "*All bills, salaries, accounts, payrolls, and claims of any kind against the Institute within the approved budget of the year shall be examined and approved by the Secretary or such officer or employe of the Institute whom he may designate. Any such payments not included in the approved budget shall be examined by the Finance Committee and signed by at least one member of the Committee. The Committee shall not authorize any payments in excess of appropriations. If at any time any of the appropriations seem in danger of being insufficient, the Committee shall so report to the Directors.*"

The above suggested changes will be acted upon by the Board at its meeting on April 16. ★ ★ ★

Student Chapter Approved

Recognition of a Student Chapter of AIME at the Wisconsin Institute of Technology at Platteville, Wis., was approved at the meeting of the Executive and Finance Committees on Jan. 9.

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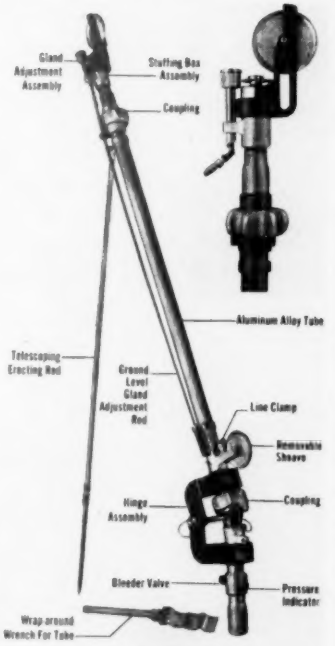

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Domestic Production in 1951

Continued from Page 12, Section 1

West Texas Area with the discovery of several fields in limestone of Pennsylvanian Age, some of which may become of major importance. Many fields also were discovered along a trend just east of the Central Basin Platform in reservoirs of Lower Permian, Pennsylvanian, and Ordovician Ages, which also will tend to maintain the position of the West Texas Area as the major source of crude oil in the United States.

Drilling activity continues to increase rapidly in the San Juan Basin, or Four Corners Area, which centers around the junction of New Mexico, Colorado, Utah, and Arizona. The majority of the discoveries made in this area during 1951 were gas fields. The reservoirs from which gas is produced are similar in deposition to those in the Spraberry trend in that they probably will cover large areas although the individual wells do not have large producing capacities. Although few deep wells have been drilled with respect to the large areal extent of the region thought to be favorable for production of oil or gas, some 46 fields or producing areas have been discovered to date, of which almost one-half have accumulation occurring as a result of stratigraphic traps.

The majority of the proved gas reserves in this area are in the New Mexico portion of the basin. The rate of exploration and of discovery has been accelerated greatly with the opening of the California market to producers in this area. Most of the gas discovered to date contains little or no sulphur and has been found in porosity variation traps in sandstones of Cretaceous Age. It is probable that continued exploration will discover at least four times as much gas reserves in the Four Corners region as drilling to date has proved present.

New Fields in Anadarko Basin

Development in the Anadarko Basin, which centers in western Oklahoma and extends into the Texas Panhandle and western Kansas, continues to draw the attention of the industry. Discovery of more than 25 new oil and gas fields and new producing areas during 1951 in this basin indicates that considerable future exploratory activity will take place in search for additional reserves. The accessibility of this area to existing marketing facilities, both for oil and gas, makes it of primary importance.

The Great Basin Area of Nevada was the scene of the greatest amount of geological exploratory activity in the Pacific Coast area outside of California. No discoveries were made in 1951 although 10 wells were drilled and abandoned and two wells were drilling at the end of the year. In Arizona seven wells were drilling at the year's end and in Oregon three wells were drilled and abandoned. In the State of Washington, one oil well was completed with a peak production of 60 B/D of 45° API gravity crude oil but production rapidly decreased and at the end of the year it was not possible to keep the well on production even at low rates. It is expected that additional drilling and exploratory work will be carried on in this state in 1952. In California, 577 exploratory wells were drilled, of which 332 were new-field wildcat wells. This compares with 489 exploratory wells drilled in 1950. Seven new oil fields and two gas fields were discovered during the year and important extensions, or new reservoirs, were added in 11 older fields. Based on data available at this time, it is doubtful that the reserves of these fields, reservoirs, and extensions will equal production during the year. It is believed, however, that reserves in California will show an increase for the year when adjustments in reserves in older fields are considered.

A discovery early in 1952 of oil in southern Alabama at relatively shallow depths indicates the possibility of the addition of another important producing area to the oil provinces of the United States. Production in Alabama previously was from fields located in the western part of the state near the Mississippi line. Continued exploration is expected in this area during the coming year.

Exploration and development continued at normal rates in the other producing areas of the United States. During 1951 considerable increases were noted in the installation of pressure maintenance programs in several of the major fields in the Southwest, and also in the installation of secondary recovery programs in many of the nearly depleted fields in the Midcontinent and Southwestern areas.

In spite of somewhat inadequate supplies of steel and tubular goods, results of developments in the petroleum industry during 1951 indicate that the dominant position of the United States in the world petroleum supply and demand picture will be maintained and possibly strengthened during the years to come. ★ ★ ★

Correction

On page 24 of the Petroleum Transactions Section of the January issue (Mobility Ratio — Its Influence on Flood Patterns During Water Encroachment) the sentence beginning on line 7 should read: "Specifically, for example, in the case of gas cycling (isothermal flow) the voltage should represent P^2 and the current should represent mass gas flow (or volume gas flow under standard conditions)."

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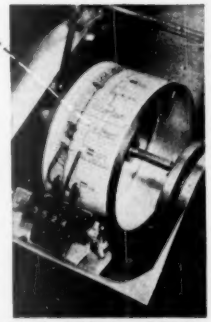

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	Page
A-1 Bit & Tool Co. *Calvin L. Clausel, Jr., Houston*	Sec. 1—20
Axelson Manufacturing Co. *Heintz & Co., Los Angeles, Calif.*	*
Baash-Ross Tool Co. *Dozier-Eastman & Co., Los Angeles, Calif.*	*
Baroid Sales Division *Darwin H. Clark Co., Los Angeles*	Sec. 1—14
Baker Oil Tools, Inc. *Theo. M. Martin Co., San Gabriel, Calif.*	Sec. 1—8, 9
Barret, William M., Inc. *Bozell & Jacobs, Shreveport, La.*	Sec. 1—16
Black, Sivalls & Bryson, Inc. *R. J. Potts-Calkins & Holden Adv., Kansas City, Mo.*	Sec. 1—19
B and W Incorporated *Lester C. Nielson Co., Huntington Park, Calif.*	Sec. 1—5
Clark Bros. Co., Inc. *Harold Warner Co., Buffalo, N. Y.*	*
Cooper-Bessemer Corp. *Griswold-Eshleman Co., Cleveland, Ohio*	*
Core Laboratories, Inc. *Duvall Williams, Dallas, Tex.*	Sec. 1—4
Dale Company *Lester C. Nielson Co., Huntington Park, Calif.*	Sec. 2—5
Dowell Incorporated *MacManus, John & Adams, Inc., Detroit, Mich.*	Sec. 1—10
Eastman Oil Well Survey Co. *Ted Workman Advertising, Dallas, Tex.*	*
Geograph Co., Inc. *Lowe Runkle Co., Oklahoma City, Okla.*	Sec. 2—7
Halliburton Oil Well Cementing Co. *Hill & Christopher, Los Angeles, Calif. Bachrodt, Newell, O'Kane and Gano, Chicago, Ill.*	Sec. 1—2, Sec. 2—6, Third Cover
Infilco, Inc. *Ruthrauff & Ryan, Hollywood, Calif.*	*
Johnston Testers *Wallace Davis & Co., Houston, Tex.*	Sec. 1—13
Keystone Development Corp. *Brennan Advertising Agency, Houston, Tex.*	*
Lane-Wells Co. *Darwin H. Clark Co., Los Angeles, Calif.*	Fourth Cover
Larkin and Co. *Peter Baycura Adv., Butler, Penn.*	*
Lufkin Foundry & Machine Co. *Cudlipp Advertising Agency, Lufkin, Tex.*	Sec. 1—7
Magnet Cove Barium Corp. *Rives, Dyke and Co., Houston, Texas*	*
McCullough Tool Co. *R. P. Casterline Advertising, Los Angeles, Calif.*	*
Lee C. Moore Corp. *Watts, Payne Advertising, Tulsa, Okla.*	*
Oil Base, Inc. *Dozier-Eastman & Co., Los Angeles, Calif.*	*
Otis Pressure Control, Inc. *Dan Goodrich, Dallas, Tex.*	Sec. 2—3
Pelton Water Wheel Co. *Edward A. Stratman Adv., Huntington Park, Calif.*	Sec. 1—1
Professional Services	Sec. 1—6
Schlumberger Well Surveying Corp. *Rives, Dyke & Co., Houston, Tex.*	Second Cover
The Second National Bank, Houston, Tex. *Gano, Bachrodt, Edwards, Inc., Houston, Tex.*	*
Sperry-Sun Well Surveying Co. *Wallace Davis & Co., Houston*	*
Sinclair Research Laboratories, Inc. *Kenyon & Eckhardt, Inc., Adv., New York*	*
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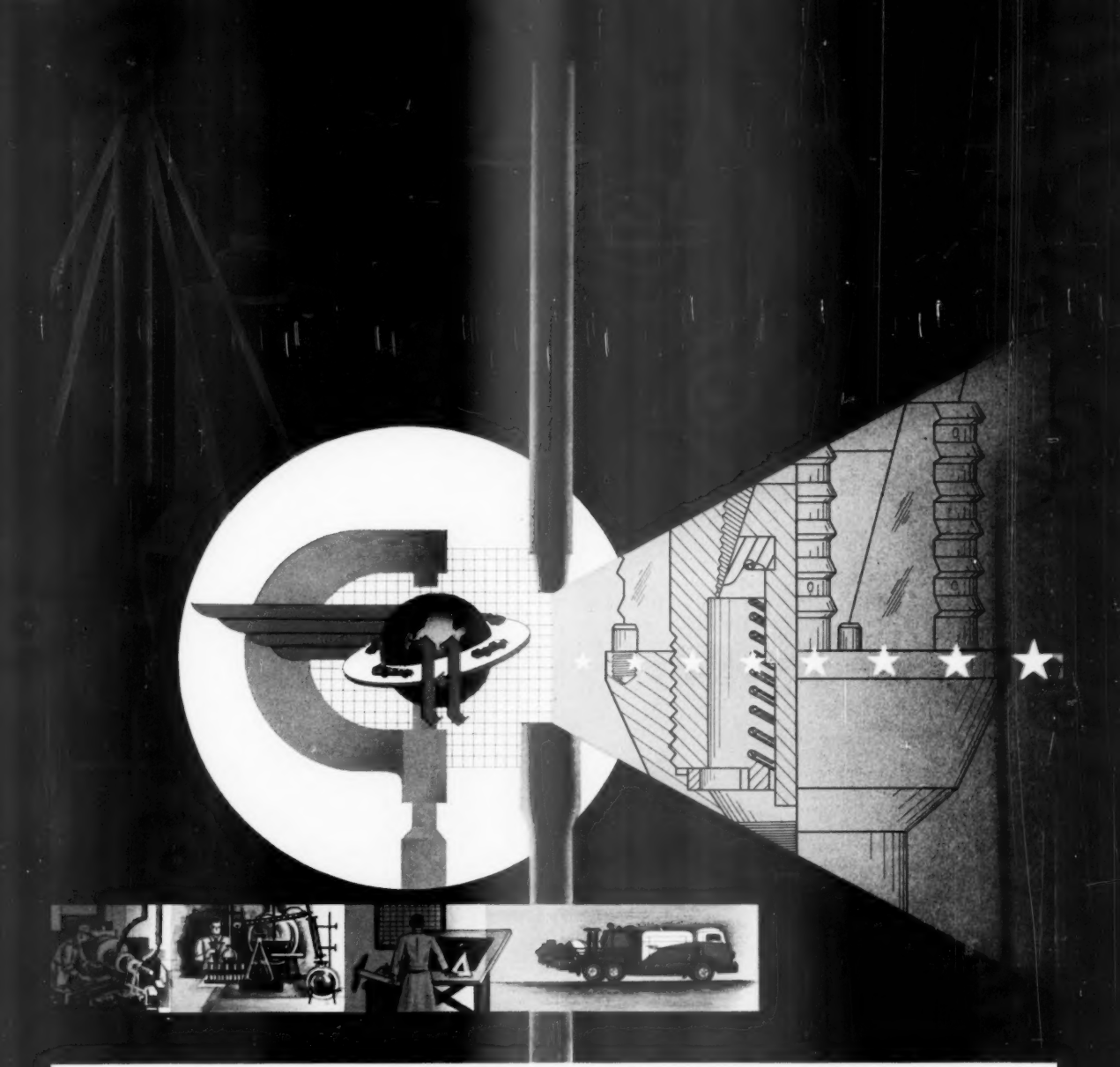

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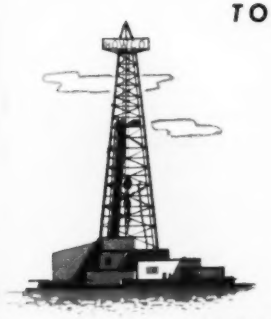

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